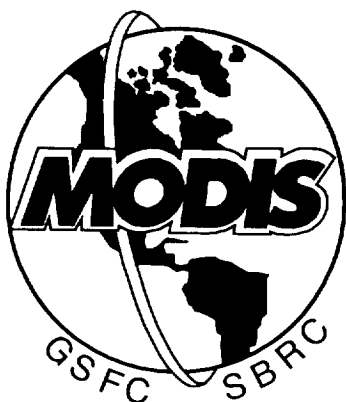


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MODIS Technical Report Series

Volume 1, MODIS Level 1A Software Baseline Requirements

**Edward Masuoka, Albert Fleig, Philip Ardanuy, Thomas Goff,
Lloyd Carpenter, Carl Solomon, and James Storey**



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MODIS Technical Report Series

Volume 1, MODIS Level 1A Software Baseline Requirements

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National Aeronautics and
Space Administration

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1. INTRODUCTION

1.1 Identification of Document

This document describes the baseline requirements for the Moderate-Resolution Imaging Spectroradiometer (MODIS) Level 1A software, to be produced by the MODIS Science Data Support Team (SDST) for the MODIS Science Team. The MODIS SDST objectives include the support of the MODIS Science Team Leader and Team Members in developing, implementing, integrating, testing and documenting MODIS data processing software, and thereby helping to meet the scientific goals of the Earth Observing System (EOS) effort. Specific to this effort, the SDST is responsible for the development of the Level 1A software.

1.2 Scope of Document

This document provides a complete description of the functional, operational, and data requirements for the MODIS Level 1A software. Specifically, it defines the internal requirements in terms of the data and process functional requirements of the software as well as the performance and quality engineering, safety, and security requirements. In addition, it provides the external interface requirements imposed on the MODIS Level 1A process by the Data Archive and Distribution System (DADS); Scheduling, Control, Monitoring, and Accounting (SCMA); Product Management (PM) System; and MODIS Log as well as the assumptions made in the MODIS Level 1A software on the Product Generation System (PGS). This document also provides the implementation constraints and requirements for adapting the software to the physical environment (site adaptation). An overview of the phased development of the software is also provided.

1.3 Purpose and Objectives of Document

The purpose of this document is to specify the functional, performance, and interface requirements of the MODIS Level 1A software. It has been developed to provide the basis for the MODIS Level 1A Systems Requirements Review (SRR) and the establishment of the functional baseline for the software.

1.4 Document Status and Schedule

This document, when approved, contains the official MODIS Level 1A requirements which form the basis for the design of the Level 1A software. The requirements will be updated as necessary, under configuration control, and updates of the document will be released as produced.

1.5 Documentation Organization

This document has been tailored using NASA-STD-2100-91 and NASA-DID-P200. It has been organized into the following sections. All related documentation including the MODIS programmatic documents as well as the applicable standards and guidelines are provided in Section 2. Section 3 provides the requirements approach. Section 4 describes the external interface requirements and Section 5 the internal requirements. Section 6 provides traceability

to parent's design. Section 7 describes the phased delivery approach to be used for the MODIS Level 1A software. Section 8 contains a list of acronyms for this document. Section 9 is a summary of the glossary of terms. Appendix A details the MODIS Level 1A structured specification. Appendix B contains the MODIS Level 1 development schedule, while Appendix C provides an estimate of the MODIS Level 0 and Level 1A data rates and volumes and the proposed data structures.

1.6 MODIS Overview

The overall MODIS objective is to make long-term observations for improved understanding of the global dynamics and processes occurring on the land surface, ocean surface layer, and lower atmosphere (including surface-atmosphere interactions) by exploiting the visible, near-infrared (IR), and thermal-IR spectrum with observation resolutions of 1 to 2 days and 250 m to 1 km.

The MODIS measurement objectives include surface temperature (land and ocean), ocean color (sediment, phytoplankton), global vegetation maps, global change (deforestation and desertification), cloud characteristics, aerosol concentrations and properties, atmospheric temperature and moisture structure, snow and ice cover characteristics, and ocean currents. Additional measurement objectives include chlorophyll concentration, primary productivity, sediment transport, standing water, wetland extent, vegetation properties, hemispherical albedo, bidirectional reflectance, cloud properties, and aerosol radiances.

MODIS will observe nearly the whole Earth twice a day for at least 15 years in two series of three spacecraft each. These spacecraft will be flown in 705-km circular, sun-synchronous orbits with 10:30 AM descending node and 1:30 PM ascending node equator crossings. The first launch will take place in June 1998. MODIS data products, beginning at Level 1A, are required by the members of the MODIS science team and members of the other EOS facility instrument teams, the EOS interdisciplinary investigators, and the scientific community at large. The primary data systems include the MODIS instrument and its processor (from sensor signals to data packets), the EOS platform and the Tracking and Data Relay Satellite System (TDRSS) (data transmission from the instrument through the platform and TDRS, to the ground), and the ground processing system including the EOS Data and Information system (EOSDIS). A set of definitions defining the processing stages for instrument data from sensor signal through data product are given in Table 1.

The land objective is to collect data for studies of the spatial and temporal variability in land surface properties (e.g., surface temperature, primary production, evapotranspiration, and photosynthesis, vegetation cover and phenology, snow and ice, radiative properties including radiation balance) with emphasis on problems such as desertification, regional vegetation stress due to acid rain or drought, and succession or change in vegetation species due to deforestation and anthropogenic effects.

The ocean objective is to collect data for studies of the spatial and temporal variability of ocean surface thermal and bio-optical properties (e.g., water-leaving radiances, photosynthetic pigments, sea surface temperature, flow visualization, attenuation coefficients and sea ice) with special emphasis on ocean primary productivity.

Table 1. Data Definitions	
Data Level	Data Definition
Level 0	Instrument-Data at original resolution, time order restored, with duplicates removed.
Level 1A	Level 0 data which are reformatted, with Earth location, calibration data, and other ancillary data included.
Level 1B	Level 1A data to which the radiometric calibration algorithms have been applied to produce radiances or irradiances.
Level 2	Geophysical parameter data retrieved from the Level 1B data by application of geophysical parameter algorithms.
Level 3	Earth-gridded geophysical parameter data, which have been averaged, gridded, or otherwise rectified or composited in time and space.
Level 4	Analyses of the lower levels of instrument data, generally involving detailed model calculations.

The atmosphere objective is to collect data for studies of tropospheric dynamics, climatology, and chemistry as obtained through observations of cloud characteristics (height, type, albedo, optical depth, effective droplet radius, and thermodynamic phase), aerosol properties, water vapor, and temperature.

1.7 Level 1A Software Description

MODIS Level 1A software accepts as input MODIS instrument packets that have been time-ordered, error-corrected, and with duplicates removed, during earlier Level 0 processing. The data is unpacked into full words and placed into standard Hierarchical Data Format (HDF) structures. The Earth location of each spatial element will be computed and included with the science data. Metadata and other descriptive header/summary information is generated to describe the product, which is archived at the Goddard Space Flight Center (GSFC) Distributed Active Archive Center (DAAC). The Level 1A product is the primary EOS archive of MODIS instrument data, and the entry point for all higher-level standard product generation. By definition and design, Level 1A data is fully reversible to Level 0 data, guaranteeing the ability for the removal of all processing artifacts in the event of future reprocessing cycles. The Level 1A software is designed to process MODIS instrument data in all operating modes, including during ground calibration and at spacecraft integration, as well as for quick-look processing for three concurrent MODIS spacecraft.

2. RELATED DOCUMENTATION

2.1 Parent Documents

- NONE

2.2 Applicable Documents

- NASA-STD-2100-91, NASA Software Documentation Standard, Software Engineering Program, dated July 29, 1991
- NASA-DID-P200, Requirements
- SEL-81-305, Recommended Approach to Software Development, Revision 3, dated June 1992
- EOS Science Software Developer's Handbook
- *Structured Analysis and System Specification*, Tom Demarco, Yourdon Press, 1979.
- Strategies for Real-Time System Specification, Derek J. Hatley and Imtiaz Pirbhai, Dorset House, 1987

2.3 Information Documents

Information in the following documents is not binding.

- DoD-STD-2167A, Defense System Software Development, dated 29 February 1988
- MIL-STD-1521B, Technical Reviews and Audits for Systems, Equipments, and Computer Software, dated 1 June 1985
- MODIS Level 1A Data Processing System, Revision 1, MODIS Data Study Team, dated April 12, 1991
- MODIS Software and Data Management Plan (draft), dated August 28, 1992
- MODIS Science Computing Facilities (SCF) Plan (draft), dated October 20, 1992
- MODIS Science Data Support Team (SDST) Coding Recommendations for the MODIS Science Team (draft), dated April 10, 1992

2.4 Other Related Documents

- MODIS-HIRIS Ground Data Systems Commonality Report, NASA Technical Memorandum 100718, dated December 1988
- MODIS Information, Data, and Control System (MIDACS) Level II Functional Requirements, NASA Technical Memorandum 100718, dated December 1988.
- MODIS Information, Data, and Control System (MIDACS) Operations Concepts, NASA Technical Memorandum 100720, dated December 1988.

- MODIS Information, Data, and Control System (MIDACS) System Specifications and Conceptual Design, NASA Technical Memorandum 100721, dated December 1988.

3. REQUIREMENTS APPROACH

The SDST has performed an analysis of the MODIS Level 1A requirements. The requirements are formulated to be quantifiable and testable. Our requirements analysis approach, described below, consists of two key processes:

- Requirements Analysis and Synthesis Process
- Requirements Change Control Process

The change control process is described in the MODIS Software Configuration Plan (to be published).

3.1 Requirements Analysis and Synthesis Process

Figure 3-1 illustrates the process used to analyze and synthesize the MODIS Level 1A requirements. The following steps were taken to produce this document:

- Gathering of Information
- Interviewing of System Users
- Development of Requirements List
- Development of Requirements Analysis Model
- Iteration of the Process

3.1.1 Requirements Synthesis

The MODIS requirements for science software are given in the MODIS Team Leader Statement of Work, Execution/Operations Phase.

Over an extended period of time, the SDST gathered information about the MODIS Level 1A processing and the requirements for the datasets. The SDST interviewed the users of the Level 1A datasets and synthesized these inputs into a list of requirements and design assumptions. Later, the SDST distilled the list of requirements and design assumptions into a list of prime requirements (see sections 4 and 5). The SDST then used the prime requirements as a basis for analysis using a model. The SDST is using structured analysis with real-time extensions as the primary methodology for analyzing the MODIS Level 1A requirements.

3.1.2 Structured Analysis

The SDST has chosen the structured analysis methodology developed by Tom DeMarco, as described in, "Structured Analysis and System Specification", Tom Demarco, Yourdon Press, 1979, along with the real-time extensions defined by Ward and Mellor. The output of the structured analysis process is a structured specification. The structured specification (see

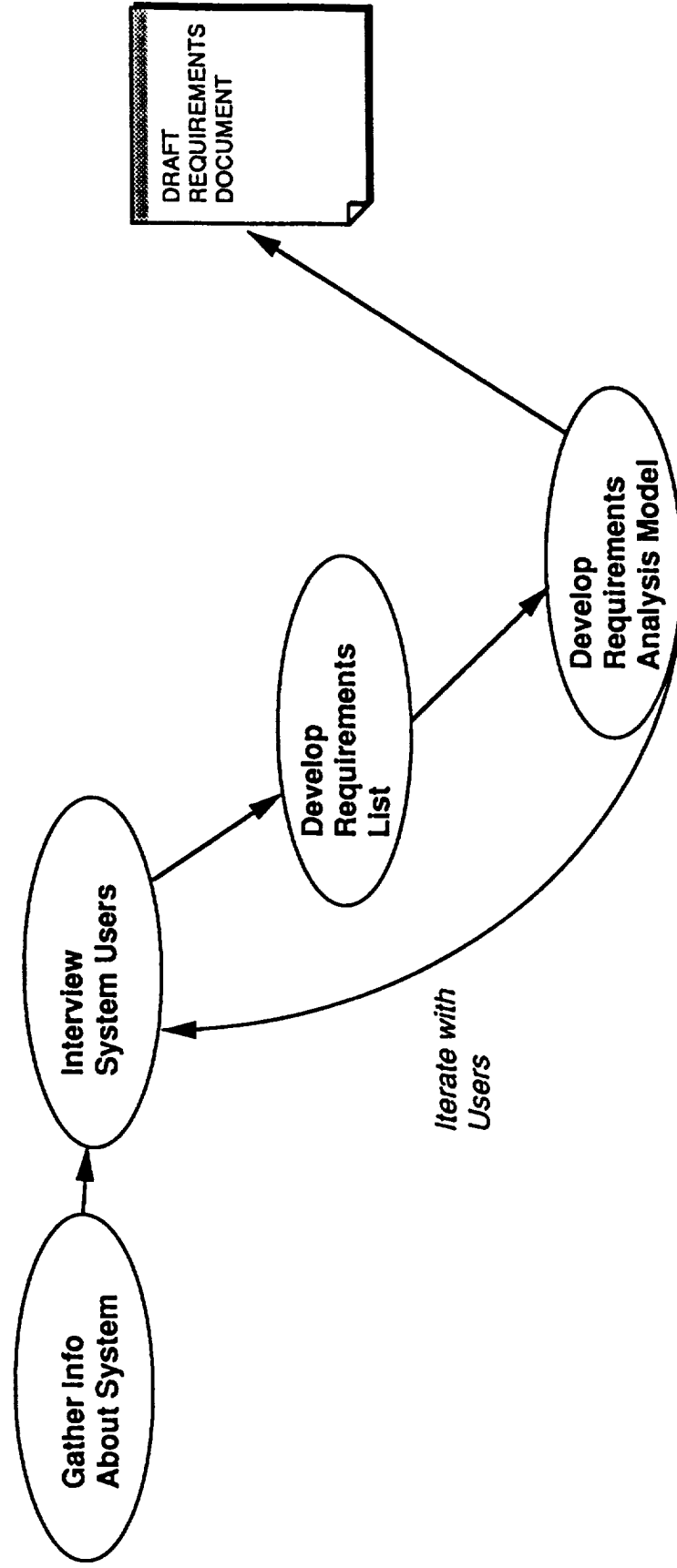


Figure 3-1. The SDST's Iterative Requirements Document Development Process Ensures That User Requirements are Fully Incorporated.

Appendix A, MODIS Level 1A Structured Specification) is graphical and hierarchical in nature. The specification represents different layers of abstraction with the top layer illustrated by the context diagram. This specification consists of an integrated set of data flows, data dictionary definitions, control flows, and transform descriptions that model the MODIS Level 1A processing. (Control flows are not generally included in data flow diagrams, but they are included here for convenience, consistent with Ward and Mellor's real-time extensions.) This model is a top-down partitioned representation of the logical functions of the system, and is easily modified and maintained. The graphic nature of the model lends itself nicely to analysis of the overall design and to identification of problems and inconsistencies in the baseline requirements. The top-level model of the system is the Layer 0 Data Flow Diagram (DFD).¹

A DFD identifies functions and the data that must flow between the functions (the interfaces). Other elements that may be identified are data stores (usually files), and external entities in the form of sources and sinks. These sources and sinks represent elements, persons, or organizations that lie outside the context of the system, but which originate or receive data flows that are part of the system. Processes are represented by numbered circles (or bubbles) and denote the transformation of incoming data into outgoing data. Data flows are represented as labelled arrows between the other elements. Further data flows are decomposed into smaller elements on lower-level DFDs. Data flows, data stores, processes, and anything else that needs defining are defined in the Data Dictionary.

As indicated previously, the top-layer processes must be decomposed to provide more detail. Each process is analyzed and described with a more detailed DFD. Each lower-layer DFD more completely describes an entire process contained in a higher-layer diagram. Sources and sinks are, traditionally, not shown on these lower-layer diagrams. These layer 1 DFDs are further decomposed into lower-layer DFDs until the desired level of detail is attained in the diagram. The processes identified at the most detailed layer are then described, using one of a number of specification techniques, in a Process Specification Data Dictionary entry. These processes are the functional primitives and form the basis for the requirements traceability which is carried throughout the development life cycle.

As noted earlier, the data flows represent pipelines through which data packets of definite composition flow. The composition of the data packets and of the data stores are described in the Data Dictionary. Each entry in the dictionary defines the structure of a data element in the DFD, including its decomposition, using a structured language adapted from the Bacus-Nauer form, into data element primitives. All elements that appear at any layer of the DFD must appear in the dictionary to assure that the model is rigorous. Some elements are built from other elements using the logical constructs of sequence, selection and iteration. Each element used to build another data element must also be defined.

¹The top-level DFD is normally called the "Level 0 DFD." Because of the use of the word "Level" to refer to data products, all DFD "levels" are here referred to as "layers."

Where applicable, control flows are used in the DFDs to represent control information flowing through the system. In the MODIS Level 1A processing, the primary control flows originate in the PGS Scheduling and Execution Subsystem.

3.1.3 CASE Tool Usage

The SDST is using CADRE's Teamwork suite of Computer Aided Software Engineering (CASE) tools to support the requirements analysis process. The products attached in Appendix A were generated directly from the Teamwork SA/RT, Structured Analysis with Real Time extensions. Teamwork automates the generation of the structured specification and supports Tom Demarco's methodology using a variety of DFD checks.

In addition to the structured analysis tools, the SDST is using CADRE's Rqt, requirements traceability tool. Rqt supports the allocation of prime and derived requirements to processes represented using Teamwork SA.

3.2 Requirements Change Control Process

Figure 3-2 illustrates the Requirements Change Control Process that the SDST will use to control the MODIS Level 1A requirements.

3.2.1 Software Requirements Review

A Software Requirements Review (SRR) was held on May 11, 1993 to provide the user community the opportunity to comment in an open forum on the requirements analysis results. The SDST incorporated the comments from the SRR attendees into this Baseline Requirements document for approval by the MODIS SDST Configuration Control Board (CCB) as the requirements baseline for MODIS Level 1A software.

3.2.2 Change Control Process

The MODIS software change control process is documented in the MODIS SDST Configuration Management Plan (to be published). The MODIS SDST CCB is co-chaired by Ed Masuoka and Al Fleig. Representatives from the EOS Project, the MODIS Science Team, and the MODIS Characterization Support Team (MCST) are invited to become members of the CCB. The CCB meets whenever a Configuration Change Request (CCR) is made by a user or developer of the system.

4. EXTERNAL INTERFACE REQUIREMENTS

4.1 Requirements Imposed on the MODIS Level 1A Process

The MODIS Level 1A process interacts with the EOSDIS system in both a functional and physical manner. Functionally, the Level 1A process receives Level 0 Data and supporting ancillary datasets from the DADS, performs control and status interactions with the PGS, writes processing status to the MODIS processing log, and produces the Level 1A output data products. All of these functions are to be accomplished physically via the EOSDIS Core System (ECS)

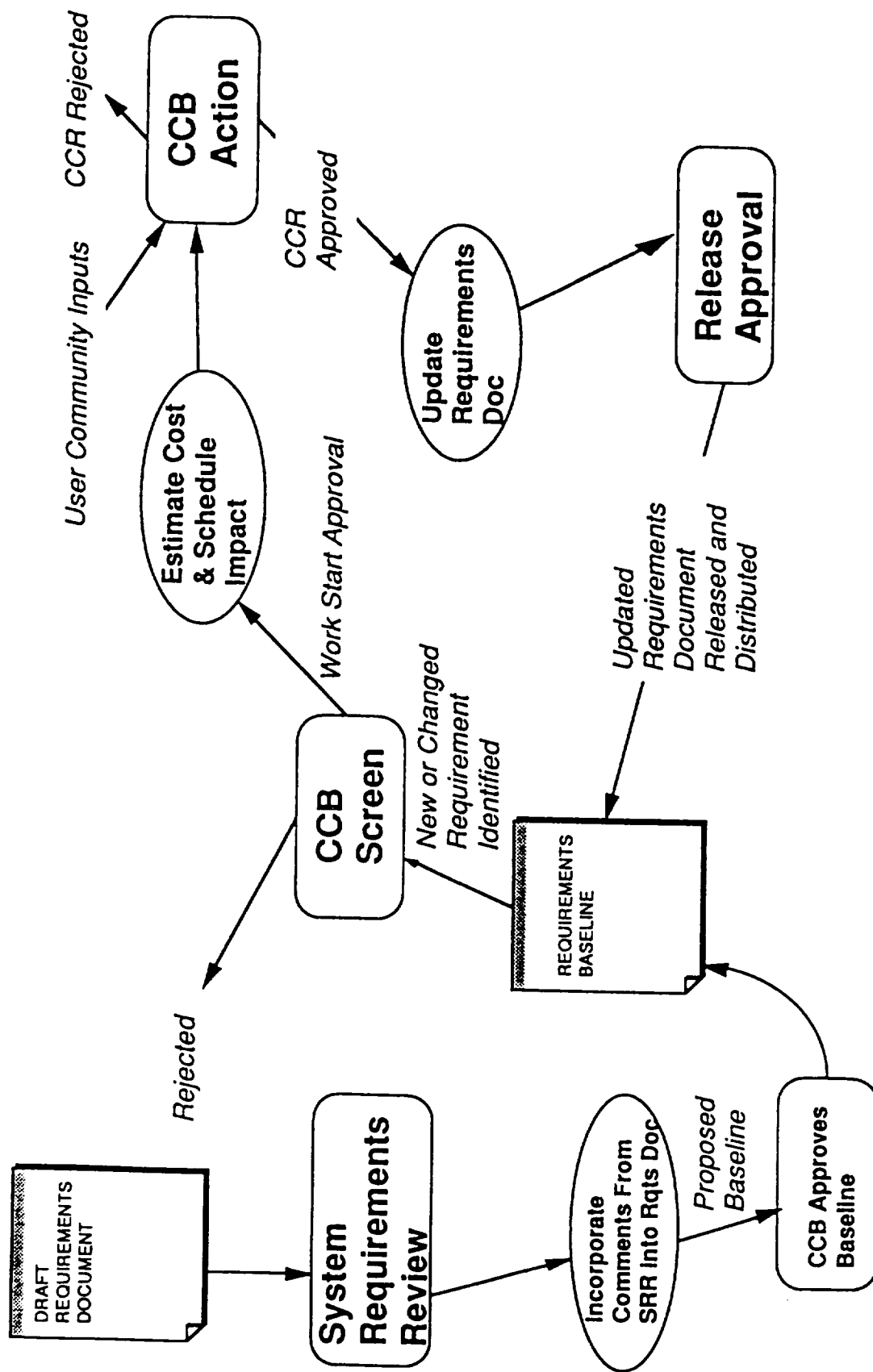


Figure 3-2. The SDST's Requirements Change Control Process Provides a Controlled Mechanism for Implementing Changes Based on User Community Input.

PGS Tool Kit function calls. This is an implementation constraint on the design of the system, the details of which are not known at the present time.

The attached MODIS Context diagram (see Appendix A) illustrates the relationship of the MODIS data processing with the external entities to the MODIS processes. For the purposes of completeness, we have chosen to include the context diagram of the entire MODIS data processing software. The Level 1A context is shown in the layer 0 DFD. The external entities are the functions that are not a part of the MODIS software effort. The requirement items in this section are categorized by the external entities to the MODIS Level 1A process as shown in the Context Diagram and are limited to the functionality of the design. Implementation techniques and requirements are not included in this document but will be included in the Interface Control Document.

4.1.1 Data Archive and Distribution System

The DADS is the storage area for all input and output data products ingested or produced by the MODIS Level 1A process. The DADS is the local segment at each site in the web of DAACs. It is the DADS responsibility to stage the required input data locally. A minimal set of the ancillary data required for the Level 1A process will be contained within the Level 0 Data Product. This includes the spacecraft platform position and attitude data. Additional ancillary data, such as improved sensor geometric correction parameters, refined platform orbit and attitude, and digital terrain elevation data will be used, when available, to improve accuracy of the generated Earth location data. These additional ancillary datasets, archived by the DADS and accessed via the PGS Tool Kit, will be staged to the MODIS Level 1A processor prior to process execution. The MODIS Level 1A process will not specifically request the DADS to stage Level 0 data, these data having been obtained before Level 1A processing begins.

- **IF01: MODIS Level 1A Input Data.** The MODIS Level 1A process shall ingest the MODIS Level 0 instrument data packets containing all instrument generated data with embedded spacecraft position and attitude, and a data transmission accounting packet generated by the EOS Data and Operations System (EDOS). All MODIS instrument data are contained within the Level 0 data packets. The Level 1A process will assemble these packets into an organized computer data structure (scan cube) as described in section 5 of this document and further detailed in Appendix C--MODIS Data Rate and Volumes with the proposed Computerized Data Structure, latest edition. The accounting data produced by the EDOS will be included as part of the Level 0 Data Product and will contain the origination and quality indicators derived by EDOS during the reconstruction of the instrument packets from the TDRSS transfer packets. Data exchange and handshaking will be between the MODIS Level 1A process and the PGS tool kit. The DADS will perform all data staging.
- **IF02: MODIS Level 1A Ancillary Input Data.** The MODIS Level 1A process shall read the ancillary input data required to generate standard Level 1A products. The DADS will archive the ancillary datasets needed to produce standard products, such as sensor geometric correction parameters, refined platform orbit and attitude data, Digital Elevation Model (DEM) data, and Earth geoid data. Access to these ancillary datasets will be provided by the PGS Tool Kit. Copies of ancillary datasets which do

not change or change only infrequently (e.g., DEM and geoid data) may, for performance reasons, be maintained locally by the PGS Level 1A processing system to limit the data staging requirements for each product. Updates to these local ancillary datasets would occur only as changes were made to the master data in the DADS.

- **IF03: MODIS Geometric Distortion Data.** The MODIS Level 1A process shall output measured geometric distortion data. The MODIS data processing system will include a geometric correction function which will generate estimates of the residual biases in the parameters which describe the internal geometry of the MODIS sensor and its relationship to the EOS platform (see requirement FN09). The MODIS Level 1A process will support this bias estimation by measuring the residual geometric error in a subset of the Level 1A products during routine product generation. These distortion measurements will be analyzed at the TLCF to improve the accuracy of and to track variations in the sensor geometric correction parameters over time. Improved values of the geometric correction parameters will periodically be provided to the DADS for archive as an ancillary data set.

4.1.2 Scheduling, Control, Monitoring, and Accounting (SCMA)

The SCMA activities, included as part of the ECS PGS process, interface with the MODIS Level 1A process in two ways: 1) it serves as control to the MODIS system (it sends messages to the MODIS process) and 2) it receives processing status information (messages from the MODIS process). This messaging performs five functions: 1) the initiation of execution, 2) the suspension of execution, 3) the resumption of execution, 4) the cancellation of execution, and 5) the requesting of status processing information. Reprocessing will be performed as part of the 'initiation of execution', function number 1) above.

- **IF04: Initiate Execution.** The MODIS Level 1A process shall accept an initiation message from the ECS PGS indicating the mode of processing and identification of input data, as predefined by the MODIS instrument team. The MODIS process (a process is a program in execution) obtains this message from the SCMA before any other processing steps have been taken. This message will contain the MODIS processing mode (standard, reprocessing, or quick look), input file names (or file pointers for the Level 0 or Level 1A to be reprocessed if applicable), and data descriptors (orbit number, TDRSS contact number, data quantity, etc.). This allows the MODIS process to calculate the sizing of the output product.
- **IF05: Cancel Execution.** The MODIS Level 1A process shall have the ability to terminate execution upon receipt of a termination signal from the ECS PGS. The MODIS process will have the ability to perform an orderly abort in which the datasets are properly posted and closed, processing log entries are posted, and Metadata are fully appended. This is contrasted with a normal termination in which the MODIS Level 1A process automatically posts and closes MODIS generated datasets and passes ownership of those datasets to the PGS Product Manager.

- **IF06: Post Processing Termination Report.** The MODIS Level 1A process shall generate a report to the PGS containing final accounting information. This is the final accounting message to the SCMA, after all processing has been completed and all resources (memory, files) have been de-allocated (posted and closed), that indicates the termination status of the MODIS process. It is posted to the SCMA upon MODIS termination. This accounting message contains an indication of the quality of the output data products , being careful not to duplicate information automatically generated by the PGS toolkit.
- **IF07: Alarm Messages.** The MODIS Level 1A process shall have the ability to generate alarm messages in the event of data or instrument problems. This class of messages indicates that a serious problem has occurred within the MODIS process that could lead to the generation of invalid data. The contents of the message indicates the nature and severity of the problem. The message is expected to contain indicator flags with predetermined error types in addition to ASCII contents . These messages are also logged to the MODIS processing log.
- **IF08: Event Messages.** The MODIS Level 1A process shall generate messages for informational purposes . This is a class of messages that are informational in nature and do not affect the quality of the output data products. These messages are also posted to the MODIS processing log. A usage example of this facility might inform the Advanced Spaceborne Thermal Emission and Reflection (ASTER) team of MODIS-detected volcanic activity.
- **IF09:** The MODIS Level 1A process shall use as input only those parameters and input datasets as directed by the ECS PGS (scheduler).
- **IF10:** The design of the MODIS Level 1A processing system shall not preclude the concurrent execution of multiple processes.

4.1.3 Product Management System (PMS)

This function, within the PGS, provides the PGS with the opportunity of accessing the MODIS Level 1A output data products, appending externally generated Metadata parameters, and transferring the data products to the appropriate DADS.

- **IF21: MODIS Level 1A Standard Data Product.** The MODIS Level 1A process shall create the MODIS Level 1A Data Product. The MODIS Data Product contains all instrument data, as opposed to the metadata product which contains descriptors that synopsise the contents of the Data Product. The requirements for the content of this output product is further described in section 5.1.2 of this document. A performance issue to be considered would be the shared staging of the output products for the convenience of the remaining processes in the MODIS processing chain before conversion to the HDF format.
- **IF22: MODIS Level 1A Quick Look Data Product.** The MODIS Level 1A process shall create the MODIS Level 1A Quick Look Data Product. The Quick Look

product will have the same format as the standard Data Product, but will not be as rigorously quality tested or padded to full orbit boundaries. It will contain an integer number of full scan cubes and a quick look identification in the Data Product header.

- **IF23: MODIS Level 1A Output Metadata.** The MODIS Level 1A process shall create the MODIS Level 1A Metadata. The MODIS Metadata contains a synopsis of, and descriptors for the associated MODIS Data Product. Level 1A Metadata consists of the Level 0 Metadata (EDOS accounting) to which the Level 1A information is appended. The specific contents of the MODIS Level 1A Metadata will be defined by the EOS project and the MODIS science community. The metadata requirements are further described in section 5.1.2 of this document.
- **IF24: MODIS Level 1A Output Product Integrity.** The MODIS Level 1A process shall appropriately post the output data to non volatile storage. At processing 'check points', the MODIS Level 1A process will write the current data from memory to the storage media. This will allow a minimum of reprocessing to be performed in the event of an abort (for example, a power failure). For example, the check point could be at the completion of one or more scan cubes and would post both the Data Product and the Metadata.

4.1.4 MODIS Log

This entity supports the availability of current MODIS processing knowledge to the various Science Computing Facilities (SCF) and the MODIS Team Leader Computing Facility (TLCF). Processing knowledge includes the temporal and spatial extent of acquired MODIS data, error conditions encountered, instrument and processing modes, processing and instrument events, etc. It is additionally used as an audit trail in the legal sense.

- **IF25: MODIS Processing Log.** The MODIS Level 1A process shall post all relevant processing information to the MODIS Processing Log, in order to track product generation history. This MODIS log, either common to all the MODIS processes or unique to each MODIS process, contains an audit trail of time ordered MODIS processing events. The contents of this log file are written by MODIS processes and can be examined, but not altered, by any other process. The location of and access method to this processing file is TBD and may be influenced by performance concerns.

4.2 PGS Assumptions Made by the MODIS Level 1A Process

These PGS-related assumptions are derived from the current design philosophy as outlined in the MODIS Data Rate, Volume, and Structures document.

- **IF26: Time Determination.** The MODIS Level 1A process shall be able to obtain the current time. The current time is used to time stamp the entries into the MODIS processing log and the processing times in the data products.

- **IF27: Time Conversion.** The MODIS Level 1A process shall be able to convert among time bases. Conversion among time bases allows the MODIS process to convert instrument and spacecraft time into the formats required for the MODIS data products.

NOTE: As the MODIS Level 1A design matures, other assumptions may be made on the PGS.

5. INTERNAL REQUIREMENTS

The requirements in this section are directed toward the internal functional aspects of the MODIS Level 1A design. Requirements directed toward entities that are external to the MODIS Level 1A design are contained in Section 4 of this document.

5.1 Process and Data Requirements

The following functional requirements list the categories of functions that the MODIS Level 1A process will provide while the data requirements specify the contents of the input and output data products.

5.1.1 Functional Requirements

- **FN01: Level 1A Data Product Reversibility.** The MODIS Level 1A Data Product shall be reversible to the MODIS Level 0 Data Product as received by the Level 1A process. Reversibility will include all ancillary and engineering data. Packets that do not pass the CRC will be thrown away. The MODIS Level 1A process will not alter the input data in any way that results in the destruction of any of the original data content. This allows the MODIS Level 1A Data Product to be the definitive archived product in place of the MODIS Level 0 data packets.
- **FN02: Level 1A Data Product Header.** The MODIS Level 1A Data Product shall produce a Data Product header for each orbit. A single header data structure will be created by the MODIS Level 1A process and incorporated into each unit (dataset) of the output Data Product. Information in the header will be a subset of the information in the Metadata.
- **FN03: Level 1A Science Content.** The MODIS Level 1A process shall execute limited science software to detect quick reaction events (e.g., volcanoes or forest fires). The MODIS process will execute simple science software on the raw counts values obtained from specified data channels and generate event messages to the ECS PGS. For example, this facility can be used for volcano detection to allow the ASTER instrument to be scheduled for detailed volcano examination or large scale forest fire detection.
- **FN04: Instrument Operating Modes.** The MODIS Level 1A processing program shall handle all instrument operating modes. The MODIS instrument has two main modes of data operation: day mode and night mode, with several sub-modes for calibration purposes. The telemetry format has two differing data packet lengths in

which several types of data can be contained. For the purpose of creating the Level 1A Data Product, the two main modes will produce a common scan cube contained in a data structure that will accommodate all the types of data produced, including the scanned Earth viewing science data, scanned calibration sources, engineering data of all types, and the spacecraft platform position and attitude asynchronous data. Data structure contents are further specified in the Data Requirements section of this document.

- **FN05: Data Transmission Modes.** The MODIS Level 1A process shall process quick look and standard MODIS Level 0 data transmissions. The MODIS quick look data are designated by a quick look flag within the data packets. It is used by the EDOS store and forward switching system to facilitate the timely routing of MODIS packets to the MODIS Level 1A process. There are currently no design requirements for the quick look data that are different than normal standard processing other than a relaxation of the quality checking and a descriptor in the header indicating that the output Data Product is a quick look product. Having the standard and quick look data processing in a common executable insures that a single set of software is employed.
- **FN06: Level 1A Metadata Philosophy.** The output MODIS Level 1A Metadata shall contain all the MODIS Level 0 metadata with Level 1A information appended. The Level 1A Metadata Product will be a super set of the input Level 0 accounting data (Level 0 Metadata). The philosophy of Metadata products is to keep as much relevant information as possible to allow quick, self-contained, determination of the processing history or pedigree of the each Data Product. This will be facilitated at each processing stage by retaining the prior metadata and appending the new processing information. The Metadata contents are delineated in the following section.
- **FN07: Level 1A Earth Location.** The MODIS Level 1A process shall generate Earth locations for each spatial element in the output product. The MODIS Level 1A process will compute geodetic positions, satellite vectors, and solar angles for each spatial element (1 kilometer IFOV) in the Level 1A dataset. These Earth locations will be based on the best ancillary data available. These ancillary datasets include geometric correction parameters provided by the MODIS geometric correction activity, refined platform orbit and attitude data generated by the Flight Dynamics Facility for selected orbits, and terrain elevation data supplied by the EOS project. Although the Level 1A process will provide the capability to use ancillary data from external sources when available, it will also be capable of generating nominal geolocation data in the absence of any of the ancillary datasets using solely the Level 0 data. The source and quality of the ancillary datasets will be indicated in the data product header and quality arrays respectively.
- **FN08: Level 1A Reprocessing.** The MODIS Level 1A process shall reprocess Level 1A products without repeating unnecessary steps for the following cases:
 - FN08A: Level 1A Science Data Reprocessing. When the Level 1A process is rerun on existing Level 1A MODIS science data, for example, to perform

additional data quality checks incorporated in a new revision of the Level 1A software, it shall have the capability to use the existing geolocation data rather than regenerating it.

- FN08B: Geolocation reprocessing using improved instrument or platform information. Knowledge of the internal instrument geometry and the sensor to platform alignment will improve with time as the MODIS instrument is better characterized. Datasets which have already been processed to Level 1A may be reprocessed to take advantage of this better geometric correction data or of more accurate ephemeris or attitude data. This reprocessing will start with Level 1A input data and will replace only the Earth location portion of the Level 1A dataset.
- FN08C: Geolocation reprocessing using improved digital elevation data. The quality of the ancillary digital elevation and geoid data used to generate the Level 1A Earth locations will improve over time as the global DEM is refined. Previously processed Level 1A datasets may be reprocessed to take advantage of this improved ancillary data. This reprocessing will use the existing geolocation information as a starting point from which to compute refined Earth locations, to reduce the processing load.
- FN09: **MODIS Geometric Correction.** The MODIS Level 1A process shall use ground control points to measure residual geometric error, to support the estimation of static and slowly varying biases in the platform and instrument geometry. Residual biases in the prelaunch values for the parameters which describe the internal geometry of the MODIS sensor and its relationship to the EOS platform as well as unknown but characterizable dynamic errors, will limit the accuracy of the Earth locations generated for MODIS Level 1A data products at launch. The MODIS data processing system will include analysis tools that support an ongoing geometric correction effort to estimate the static biases and monitor their stability, and measure the magnitude, time persistence, and repeatability of the dynamic geometric errors affecting the MODIS Level 1A data products. This geometric error analysis will utilize SRCA data and data from external sources such as ground control points. The MODIS Level 1A process will use control points to measure the residual geometric error in selected products. The off-line geometric analysis activity will use multiple sets of these error measurements to estimate geometric correction parameters. Improved estimates of the MODIS geometric correction parameters will be provided to DADS for archive on a periodic basis. The frequency with which datasets must be analyzed is TBD.

5.1.2 Data Requirements

- FN10: **Level 0 Input Data Checking.** The MODIS Level 1A process shall perform input packet data checking of the following items:
 - FN10A: The Level 1A process shall verify the MODIS instrument data packet CRC. This is a check to insure that the packet information is valid. Packets that

do not have a valid CRC will be discarded. The packet ID, sequence count, or other data identifiers can not be trusted if the CRC computes incorrectly and the location of the packet within the scan cube can not be determined.

- FN10B: The Level 1A process shall verify packet IDs, sequence counters, packet sizes, and packet format. Packet IDs, sizes, and sequence counters will be used by the Level 1A process to properly place the packet data into the appropriate scan cube data structure. Packet formatting will be used to identify data components.
- FN10C: The Level 1A process shall check and account for duplicate packets. Although the standard EDOS processing will remove duplicate packets, the quick look EDOS processing on multiple TDRSS down links may produce duplicate packets. Missing packets will be flagged in the output MODIS Level 1A Data Product.

Appropriate responses to the PGS will be generated if the process detects anomalies related to the above data checks.

- **FN11: MODIS Level 1A Data Product Header Contents.** The MODIS Level 1A Data Product header shall contain information such as:

- FN11A: Address of the origination source. A complete description of the project (with contact information) which can be used to obtain all information about the dataset.
- FN11B: Project name. The name of the logical division within the project for the parties responsible for the dataset and its contents.
- FN11C: Date of the last dataset revision. Full-time stamping of the last time this dataset has been altered.
- FN11D: Software, Level 0, and ancillary data revision codes. Full descriptors of the revision of the software utilized to create this dataset.
- FN11E: Quantitative descriptors (selected metadata) of the Data Product contents. An indication of the contents of the dataset, specifying (for example) that the dataset is a remotely sensed image of the Earth in specified spectral bands covering a specified range of latitudes and longitudes in 1 km pixels for specified dates.
- FN11F: Data Quality Descriptors. A synopsis of the data quality arrays that will be contained within each scan cube.

This facility allows the dataset to be interrogated by simple ASCII editors or listers and sufficient information to be extracted by these simple editors or listers to determine the type, origination, and contents of dataset.

- **FN12: MODIS Level 1A Metadata Contents.** The MODIS Level 1A Metadata output product shall contain, as a minimum, the following:
 - FN12A: All EDOS accounting information. A possibly reformatted copy of the EDOS accounting information that is contained in the EDOS final accounting packet.
 - FN12B: EOSDIS specified contents. Metadata contents that are required of all DADS Metadata. These may be specified by EOS, the Consultative Committee on Space Data Systems (CCSDS), or other authorities.
 - FN12C: Descriptors about the MODIS Level 1A Data Product. The contents of the Metadata Product will be specified at a later date by both the ECS project and the MODIS community.
 - FN12D: Information describing the temporal and spatial domain of the dataset. A common mechanism for describing the spatial and temporal extent of archived datasets should be specified by the EOS project to support Information Management System spatial queries.
 - FN12E: All of the Data Product header contents. A repeat of all the information that will be contained in the MODIS Level 1A Data Product header. Reformatting of the header contents may be required to match Metadata content formats.
 - FN12F: Descriptors About the Level 1A geolocation Processing. Information about the sensor geometric correction parameters, the source of the platform orbit and attitude data, and the accuracy of the DEM data used in the MODIS Level 1A Earth location processing will be included in the Level 1A metadata.
 - FN12G: Parametric Earth Location coefficients. The coefficients of a simple model which relates image pixel and line number to the corresponding location at the Earth ellipsoid surface and vice versa will be included in the metadata for each Level 1A dataset. This parametric geolocation model will provide a method for rapidly indexing into the MODIS Level 1A dataset based on Earth coordinates.
 - FN12H: Input and Ancillary File Traceability. This metadata content requirement satisfies the criteria for the reproducibility of data as well as the tracking of the product generation history. It is beneficial to data users to be able to reconstruct the process, including software and dataset versions, that produced the Level 1A data to the fullest extent possible.

The Metadata are the repository for all information about the actual Data Product. It can be used as selection criteria to delineate among the various data products. Metadata will also include subjective comments in addition to objective independent observation about the corresponding Data Product. There is a one to one correspondence between the Metadata sets and the associated Data Product datasets.

- **FN13: MODIS Level 1A output Data Product Formatting.** The MODIS Level 1A data product shall conform to the EOSDIS standards for data structures and formats.
- **FN14: MODIS Level 1A Data Product Attributes.** The MODIS Level 1A Data Product shall possess the following attributes:
 - FN14A: A unit (dataset) of a MODIS Level 1A standard Data Product shall consist of a full orbit of data. This is the dataset unit for each occurrence of the output data products. The smallest obtainable data unit (granule) within a dataset occurrence will be a scan cube.
 - FN14B: A unit (orbit) of data shall begin at the beginning of the first full scan cube after the nighttime node. An orbit boundary will occur during the MODIS nighttime operating mode.
 - FN14C: Partial units and missing data shall be padded with fill data. All data are preallocated and filled with a default invalid data value when the storage for each scan cube is allocated. This occurs before any real data are placed in the allocated scan cube.
 - FN14D: A unit (orbit) of data shall contain full, complete (integer number of) scan cubes. Scan cubes will not be split or duplicated across Data Product units.
 - FN14E: All data shall be byte aligned. This follows from the use of the HDF archiving criteria. No requirement for a 12 bit data type will be imposed on the HDF library and the MODIS Level 1A process will unpack the all 12 bit data to 16 bit words.
- **FN15: MODIS Level 1A Data Product Contents.** The MODIS Level 1A Data Product shall contain the following information:
 - FN15A: Raw science data. Earth-viewing, moon-looking if the spacecraft has been tilted.
 - FN15B: Raw Solar Diffuser data. When solar diffuser is deployed; otherwise, electronic calibration data.
 - FN15C: Raw Black Body data. Ambient or heated blackbody views.
 - FN15D: Raw Space View data. Deep space viewing; occasional lunar views.
 - FN15E: Band number to data channel number translation tables. To allow for the two gains of bands 13 and 14, and the smaller spatial viewing of bands 1 through 7.

- FN15F: Spatial data quality arrays. Across track vs. along track, and along track vs. data channel to allow quality indicators to be specified at the level of each pixel, band, and detector.
- FN15G: Two Time Tags per frame.
- FN15H: Spectroradiometric Calibration Assembly (SRCA) and Solar Diffuser Stability Monitor (SDSM) Data (TBD).
- FN15I: Engineering/Memory Dumps (TBD).
- FN15J: Spacecraft Position and Attitude. Sufficient platform location and attitude data values, clustered in time about each scan cube to allow for time based interpolation.
- FN15K: Spatial Element Geodetic Coordinates. The geodetic latitude, longitude and height at which the sensor line of sight intersects the terrain surface for each spatial element (1 kilometer IFOV) in the Level 1A dataset.
- FN12L: Spatial Element Satellite Vector. The zenith angle, azimuth and range to the satellite for each spatial element in the Level 1A dataset.
- FN12M: Spatial Element Sun Angles. The solar zenith angle and solar azimuth for each spatial element in the Level 1A dataset.

5.2 Performance and Quality Engineering Requirements

The requirements in this section relate to the performance constraints of the MODIS Level 1A process and include items that result in better partitioning of the processing task and improved processing speed.

- **PR01: Processing Timeliness (PGS parent requirement).** The MODIS Level 1A data product generation shall be completed within 24 hours of the arrival of the Level 0 data. This Level 1A data product timeliness requirement is imposed primarily on the PGS scheduling activity.
- **PR02: Data Throughput Rates (PGS requirement).** The MODIS Level 1A process shall process a full day of input data and generate output data products in a TBD fraction of a day.
- **PR03: Error Detection.** The MODIS process shall continue processing upon the detection of an condition. The MODIS processing software, in conjunction with the PGS Tool Kit, will trap and properly process all exceptions that may produce an abort condition. These processing events will be posted to the MODIS processing log.

- **PR04: Data Quality.** The MODIS Level 1A process shall perform (TBD) data quality checking on the output MODIS Level 1A Data Product. Selected data values in the content of the output Data Product will be validated using techniques and criteria that will be specified at a future time. This will produce a data quality array as part of the output MODIS Level 1A Data Product. The quality array will include one or more subfields which reflect the accuracy of the Earth location data.
- **PR05: Data Product Granularity.** The MODIS Level 1A process shall provide data quality indicators for each scan cube. Every scan cube of output product will contain data quality arrays and indicators for data that is scan-cube related.
- **PR06: Maintainability.** The MODIS software shall be documented and configuration managed. Full configuration management in a distributed heterogeneous computer network will be implemented to enable revision control across the TLCF, SCFs, and ECS computer systems.
- **PR07: Portability.** The MODIS software shall be written according to EOSDIS standards. Vendor-dependent language extensions will not be used (see design goals).
- **PR08: Use of PGS Toolkit.** The MODIS software will use a subset of the tools provided by the PGS toolkit as appropriate. To reduce the cost and schedule risk to the project, the SDST recommends that EOSDIS provide the calling sequences of the tools in the toolkit as early as possible in the development life-cycle.
- **PR09: Earth Location Accuracy.** The MODIS Level 1A process shall have an absolute Earth location accuracy goal of 0.1 IFOV for the nominal 1 km resolution bands. The absolute accuracy of the Earth locations generated by the MODIS Level 1A process is primarily dependent on the quality of the geometric correction, orbit, attitude, mirror, and DEM input data. Excluding DEM errors, the MODIS processing system will seek to achieve the 0.1 IFOV accuracy goal by improving the at-launch knowledge of the static and slowly varying components of error through an ongoing geometric correction activity. The frequency with which the error estimation analysis must be performed to meet this goal is TBD.

5.3 Safety Requirements

- **OR01:** All MODIS Level 1A operational software will be under the control of the ECS, which will be responsible for all safety concerns. Critical tasks, operator intervention, processing analysis, and human factors are all ECS functions.

5.4 Security Requirements

- **OR02:** The controlled access to data and processing elements, data protection and recovery, and privacy issues are the responsibility of the ECS.

5.5 Implementation Constraints

- OR03: The MODIS implementation will be performed on the MODIS TLCF and ported to the PGS when that computer system has been placed into operation. The MODIS SDST has no current knowledge of the computer system or computer architecture to be selected.
- OR04: MODIS requires the availability of Level 0 datasets that have known data values and discrepancies for testing purposes during development on the TLCF and subsequent porting to the PGS.
- OR05: MODIS also requires an independent output product data validator.

These requirements are covered in documents written under different covers.

5.6 Site Adaptation

The MODIS Level 1A processing software will be fully encapsulated within the PGS tool kit and will therefore have no direct contact with other processes or the operating system.

5.7 Design Goals

The MODIS Level 1A process will satisfy all the requirements as set forth in this document. It will be tested in conjunction with a Level 0 packet simulator and a Level 1A data product validator. The packet simulator will include the ability to generate pseudo instrument data, accept instrument engineering model data, modify packet parameters, include simulated scene data, provide valid spacecraft position and attitude information, and alter selected engineering data. The data validator will display selected engineering data, visualize scene image data, display headers, and generate statistics. The goal of these testing systems is to create the highest reliability in the MODIS Level 1A process software.

All MODIS software components shall contain commented information that can be automatically extracted and made available to all software personnel in utilizing a common access method. Key words will be used in the software modules that will allow for the machine extraction of parts of the common software headers and other commented sections. These will be placed into a project accessible database for use by all personnel and will facilitate the reuse of previously written modules.

The MODIS software shall be generated with machine and architecture porting as a primary goal. Consideration shall be given to facilitate portability from machine to machine when designing and writing the Level 1A software. The functional modules of the MODIS software will utilize techniques that allow for their transfer to other technologies and disciplines such as real time monitoring in addition to the core requirement of the PGS implementation.

6. TRACEABILITY TO PARENT'S DESIGN

The requirements in this document are derived from the EOS Program Level 1 Requirements and the Implementation Agreement for the MODIS Team Leader, Statement of Work Execution/Operations Phase.

The MODIS Level 1A Processing is part of the overall MODIS Science Data Processing. The Context Diagram shown in Appendix A illustrates the relationship of the external entities to the MODIS Science Data Processing. The Layer 0 DFD shows the context of the Level 1A Processing with respect to the Level 1B, and Higher Level Processing in the MODIS Science Data Processing Software Suite.

7. PARTITIONING FOR PHASED DELIVERY

The MODIS Science Team Leader has assigned responsibility to the MODIS SDST for all aspects of the development of the MODIS Level 1A software. The development plan is based upon three phases, or software versions, β , V1 and V2 prior to launch. The purpose of the three phases is to:

- β Test migration from the SCF to the EOSDIS, exercise interfaces, and test execution in the operational environment.
- V1 Correct any problems in the β Version, complete operator interface, generate all messages.
- V2 Software ready for launch. Final integration, test of operations procedures, training of operations staff.

The SDST schedule for development of the three phases of MODIS Level 1A science software is given in Appendix B. The software requirements, design, and code will be developed as an iterative process involving the MODIS Science Team members. There will be substantial changes in going from β to V2.

The SDST will develop a Level 1 Test Plan and test datasets which will exercise all of the viable branches (within reason) in the code, checking for proper results. The tests will also check for proper functioning of the software in the presence of anomalous or meaningless data.

After the software has been thoroughly tested on the TLCF, the SDST is responsible for porting the software to the EOSDIS PGS and participating in the test process in the PGS.

8. ACRONYMS AND ABBREVIATIONS

ASTER	Advanced Spaceborne Thermal Emission and Reflection
CASE	Computer Aided Software Engineering
CCB	Configuration Control Board
CCR	Configuration Change Request
CCSDS	Consultative Committee on Space Data Systems
CRC	Cyclic Redundancy Check
DAAC	Distributed Active Archive Center
DADS	Data Archive and Distribution System
DEM	Digital Elevation Model
DFD	Data Flow Diagram
ECS	EOSDIS Core System
EDOS	EOS Data and Operations System
EOS	Earth Observing System
EOSDIS	EOS Data and Information System
GSFC	Goddard Space Flight Center
HDF	Hierarchical Data Format
IMS	Information Management System
IR	infrared
MODIS	Moderate-Resolution Imaging Spectroradiometer
PDR	Preliminary Design Review
PGS	Product Generation System
PM	Product Management
PMS	Product Management System
QA	quality assurance
RDC	Research and Data Systems Corporation
SBRC	Santa Barbara Research Center
SCF	Science Computing Facility
SCMA	Scheduling, Control, Monitoring, and Accounting
SDSM	Solar Diffuser Stability Monitor
SDST	Science Data Support Team
SRCA	Spectroradiometric Calibration Assembly
SRR	Systems Requirements Review
TDRSS	Tracking and Data Relay Satellite System
TLCF	Team Leader Computing Facility

9. GLOSSARY

ALGORITHM is a general or abstract approach to solving a problem. An outline of major steps to be taken in the solution expressed in English (or other natural language) and/or in pseudo-code/PDL.

ANCILLARY DATA refers to any data, other than Standard Products, that are required as input in the generation of a Standard Product. This may include selected engineering data from the EOS platform, ephemeris data, as well as non-EOS ancillary data. All ancillary data are received by the PGS from the DADS.

AT-LAUNCH PRODUCTS are data products for which science software is scheduled to be completed and operational at launch time. Generation of the at-launch products will begin as soon as data are available.

BAND is a center frequency and filter function width combination that are referenced by an arbitrary number. One channel usually measures data from one band, but MODIS has two channels of data for each of bands 13 and 14.

β VERSION SOFTWARE is the preliminary version of software used to test migration from the SCF or TLCF to the EOSDIS, exercise interfaces and test execution in the operational environment.

BROWSE DATA are subsets of a dataset other than the directory and metadata that facilitates user selection of specific data having the required characteristics. For example, for image data, browse data could be a single channel of multichannel data, and with degraded resolution. The form of browse data is generally unique for each type of dataset and depends on the nature of the data and the criteria used for data selection within the related science discipline.

CALIBRATION is the process of removing biases from the measurements. The information required to perform calibration of the instrument science data will include instrument engineering data, spacecraft or platform engineering data, pre-flight calibration measurements, in-flight calibrator measurements, ground truth data, and calibration equation coefficients derived using calibration software.

CHANNEL is the data derived from an instrument data gathering electronic channel. Channels of data may be obtained in parallel. Contrast this with a band of data.

CORRELATIVE DATA are scientific data, generally from outside sources, needed to evaluate and validate EOS data products.

DATA QUALITY REQUEST is a request issued by the PGS to a scientist at an SCF to perform quality assurance (QA) of a particular product before future processing or distribution. A time window is applied to the request in keeping with the production schedule.

DIGITAL ELEVATION MODEL refers to a numerical model which describes the elevation of the Earth's terrain surface above mean sea level. In the Level 1A processing context, it includes

no higher order terrain statistics, such as slope, although these may be required for some MODIS Level 2 data products. Global digital elevation data have been identified as a required ancillary dataset by several of the EOS AM instruments.

DOCUMENTS are the hardcopy or digitized references or records about a science software, or the data products generated by the science software. These shall be archived at the DADS.

EXECUTABLE is the result of compiling and linking a program written in a standard programming language such as C or Fortran. An entity whose action can be invoked directly from the UNIX command line.

FRAME is a set of data representing one instance of: all bands of science data and 10 along track spatial elements (day or night mode), or all bands & 10 spatial elements of solar diffuser, black body, or space view data, or specialized data from the SRCA or Engineering/Memory dumps.

GEOMETRIC CORRECTION PARAMETERS refer to the set of constants which describe the internal geometry of the MODIS instrument and its relationship to the EOS platform (for example the sensor to body alignment matrix). These parameters will be known to some precision at launch and will be refined post-launch through an ongoing geometric correction effort.

INSTRUMENT DATA are data specifically associated with the instrument, either because it was generated by the instrument or included in data packets identified with that instrument. These data consist of instrument science and engineering data, and possibly ancillary data. These data may be assembled for transmission by the instrument, or by an on-board processor of the instrument data.

INTERACTIVE SESSION DIALOG consists of messages that flow between a scientist at an SCF and the PGS that support general communication with the Integration and Test Service. This includes logins, mail messages, etc.

Level 0 DATA are raw instrument data at original resolution, time ordered, with duplicates removed.

Level 1A DATA are Level 0 data, which may have been reformatted or transformed reversibly and packaged with needed ancillary, engineering, and auxiliary data.

METADATA are data which describe the content, format, and utility of a Standard Product. It includes standard metadata (i.e., science software and calibration numbers, size of product, date created, etc.), science software-derived metadata, QA information from the PI's, summary statistics and an audit trail. Metadata are received by each DADS with the corresponding datasets. DADS validates it physically, updates it with inventory information, enters it into a distributed database (to which the Information Management System (IMS) has access), and archives it. Metadata about special products produced at SCFs shall be sent to the DADS along with their associated data products.

METADATA UPDATES are additional or changed metadata items relating to a previously delivered product.

ON TIME QA is a response to a data quality request that is received within the established production time window. It is received from a scientist at an SCF. It consists of data which will be used to complete the QA fields of the metadata. Overdue QA responses are sent directly to the DADS.

PIXEL is the smallest decomposed unique science data value. One pixel represents the data from one spatial position and one channel of data.

POST-LAUNCH PRODUCTS are data products for which science software are scheduled to be completed at some time after launch.

PRODUCT GENERATION EXECUTABLE (PGE) is either a single executable that is rebuilt at the PGS using the delivered science software, or a set of such executables embedded within a script written by the science software developers. For example, the MODIS Level 1A process, with its accompanying script language, could be an example of a running PGE.

PRODUCTION SCRIPT is a script that is written by the PGS (perhaps automatically by the scheduler). A production script controls the execution of one or more PGEs. Some of the content of a production script may be based on instructions from the science teams. For example, the PGS might create a production script to run the 1A and 1B PGEs in sequence.

QUICK-LOOK DATA are data that carry a quick-look identifier which is initially applied at the MODIS instrument in response to a request for quick processing in support of a field experiment or other special purpose. Processing is done in near-real-time as the datasets are received using the same science software as for normal processing. Calibration and quality assurance requirements are relaxed for fast turn-around. Data identified as quick-look are also processed in the normal mode with all other data for standard products.

SCAN CUBE is the three dimensions of the science data: along track, across track, and band number with ground locations, engineering data (per scan), and quality indications attached.

SCIENCE COMPUTING FACILITY is a MODIS science team member's computing facility to support science software development and testing and generation of MODIS special products.

SCIENCE DATA SUPPORT TEAM is the software support group designated by the MODIS Science Team Leader to develop MODIS science data processing requirements, develop MODIS Level 1 processing software, develop the higher-level processing shell, support the integration of team members' science software into the production environment, and provide support for the development of required plans and documentation.

SCIENCE SOFTWARE is the complete suite of items delivered by the science team to the PGS. This includes source code, build instructions (i.e., make files), documentation, test data, test procedures, and sample test results. This is the most likely replacement for "algorithm" in the

old usage. For example, we now refer to Science Software Development or Science Software Integration and Test.

SCIENCE SOFTWARE UPDATES are delivered to the PGS' integration and test environment by scientists at a SCF. They represent changes to existing production science software, or new science software to produce new Standard Products. Science software updates include the source code for the candidate science software, its associated documentation, a job step control skeleton, test datasets and expected test results.

SCRIPT is a set of instructions written in a structured language, similar to a UNIX shell language.

SPATIAL ELEMENT refers to the area covered by a single sensor instantaneous field of view (for the 1 kilometer bands) for a nominal detector in a nominal band. A single spatial element corresponds to the pixels from all bands for a given spatial position. Corrections for real band and detector misalignments from their nominal locations will be applied during Level 3 processing.

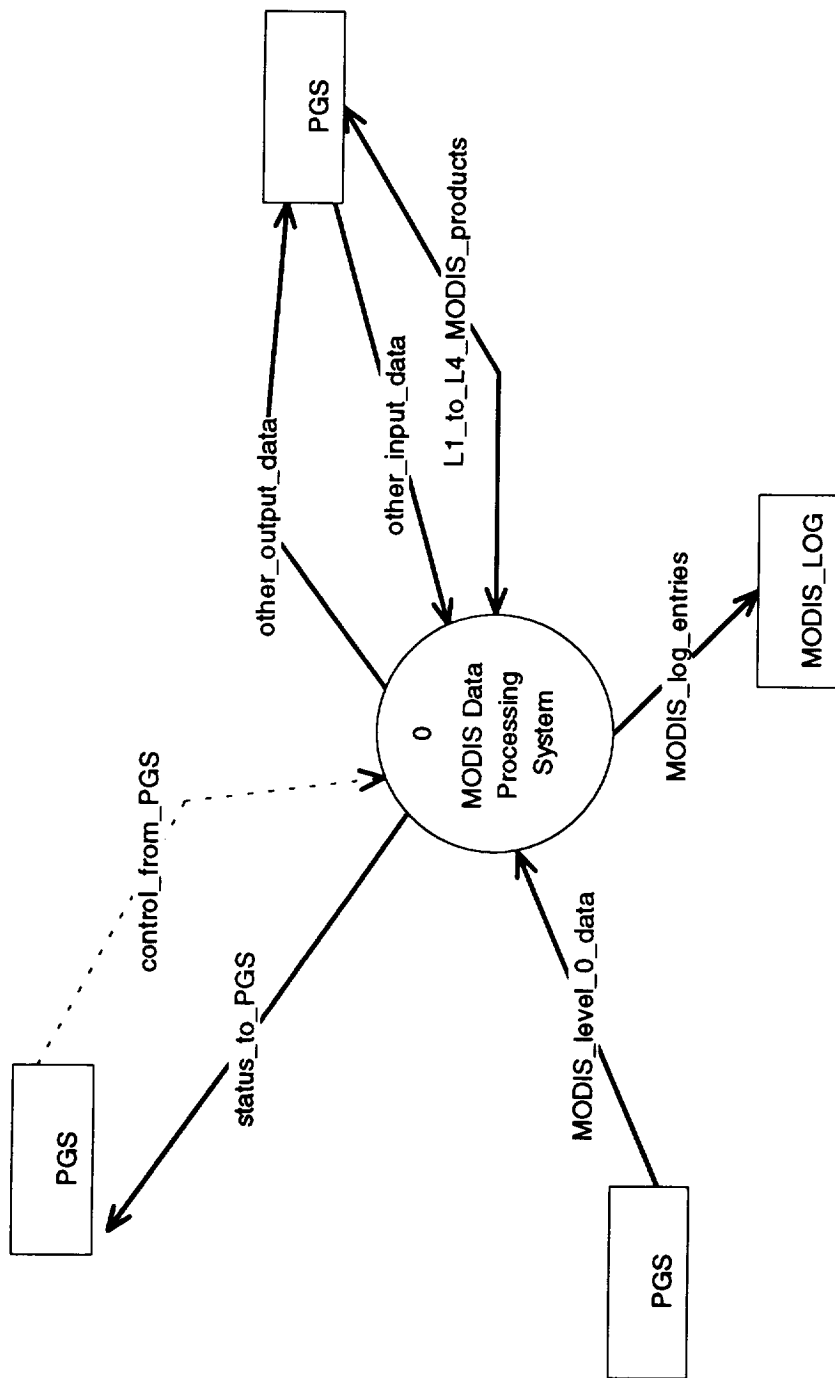
SPECIAL PRODUCTS are special science data products consisting of Level 1A, Level 1B, Level 2, Level 3, and Level 4 which are produced at the SCF or the TLCF. (See also Standard Products.) These shall be archived at the DADS and distributed to authorized requestors.

TEAM LEADER COMPUTING FACILITY is the SCF designed to provide the required computer support for the MODIS team leader. The TLCF will support MODIS Level 1A and 1B science software development, development of the higher-level processing shell, integration of team members' science software, generation of special products, science software testing, etc.

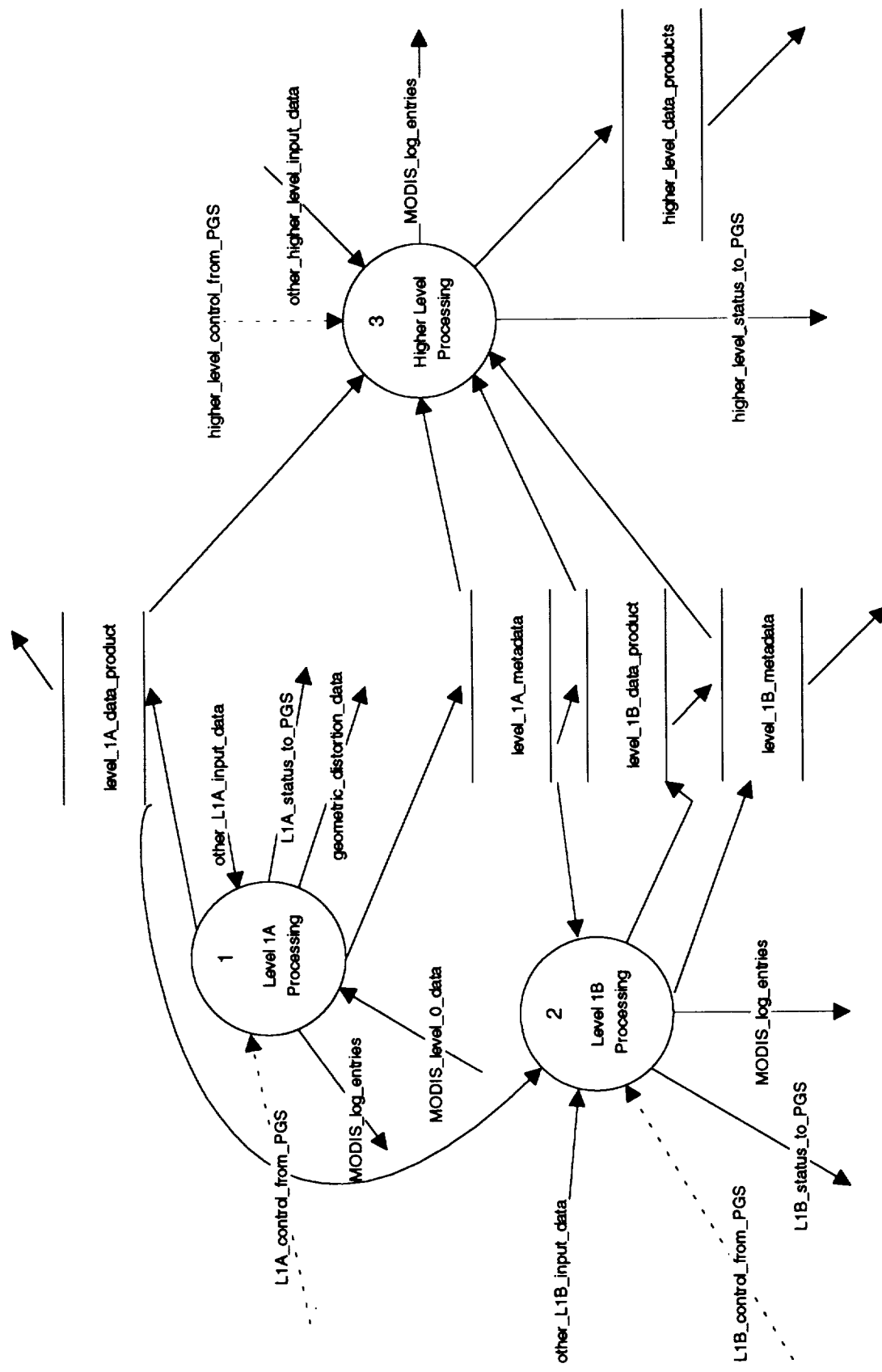
VERSION 1 SOFTWARE is used to correct any problems in the β Version, complete operator interface, generate all messages.

VERSION 2 SOFTWARE is ready for launch. It will be used for final integration, test of operations procedures, training of operations staff, etc.

Appendix A
MODIS Level 1A Structured Specification



MODIS Data Processing System



MODIS Data Processing Systems



TITLE:

Verify Level 0

INPUT/OUTPUT:

L0_packets : data_in

L0_verified_information : data_out

EDOS_accounting : data_out

processing_status : data_out

BODY:

Read L0 packets

Verify L0 packets

 check for duplicates

 check packet IDs for MODIS

 check sequence counters

 check packet sizes

 check packet format

 check MODIS packet CRC

Produce L0_verified_information

Produce EDOS_accounting

Report processing_status.

Accumulate Scan Cubes

TITLE:

Accumulate Scan Cubes

INPUT/OUTPUT:

L1A_scan_cube : data_in

L1A_orbit : data_out

processing_status : data_out

BODY:

Read L1A_scan_cube until orbit's worth of data

Format and Output L1A_orbit

Report processing_status

Write Metadata

TITLE:

Write Metadata

INPUT/OUTPUT:

geolocation_metadata : data_in

L1A_scan_cube : data_in

EDOS_accounting : data_in

level_1A_metadata : data_out

BODY:

Read EDOS_accounting

Read L1A_scan_cube

Read geolocation_metadata

Compile metadata (the contents of the metadata are TBD)

Produce level_1A_metadata

Perform Quality Checking

TITLE:

Perform Quality Checking

INPUT/OUTPUT:

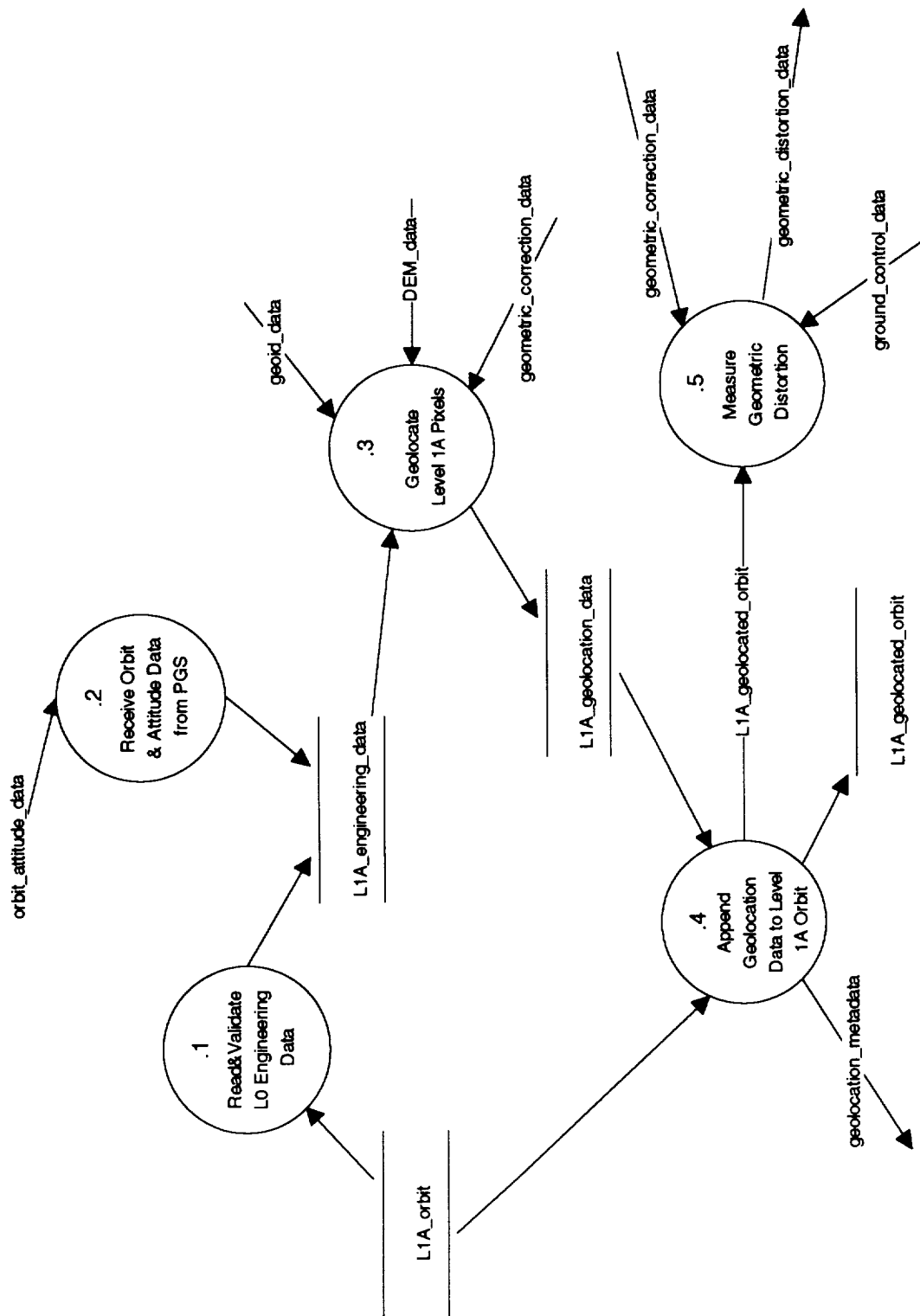
L1A_scan_cube : data_in

processing_status : data_out

sensor_data_quality : data_out

BODY:

Perform TBD Quality Checking.



Geolocate Level 1A Orbit

Read and Validate L0 Engineering Data

TITLE:

Read and Validate L0 Engineering Data

INPUT/OUTPUT:

L1A_orbit : data_in

L1A_engineering_data : data_out

BODY:

Read engineering data frames
Extract spacecraft ancillary messages
Verify ancillary data messages
 Time order ancillary data messages
 Eliminate duplicate messages
Extract and validate ancillary message subfields
 Extract orbit data
 Validate orbit data
 Extract attitude data
 Validate attitude data
 Extract solar vectors
 Validate solar vectors
Extract mirror data from engineering data frames
Validate mirror data
Extract scan timing data
Validate scan timing data
Write L1A_engineering_data
Report processing status.

Receive Orbit and Attitude Data

TITLE:

Receive Orbit and Attitude Data from PGS

INPUT/OUTPUT:

orbit_attitude_data : data_in

L1A_engineering_data : data_out

BODY:

Read orbit_attitude_data pointer

If not null

 Read orbit data

 Subset orbit data

 Validate orbit data

 Read attitude data

 Subset attitude data

 Validate attitude data

 Add orbit/attitude data to L1A_engineering_data

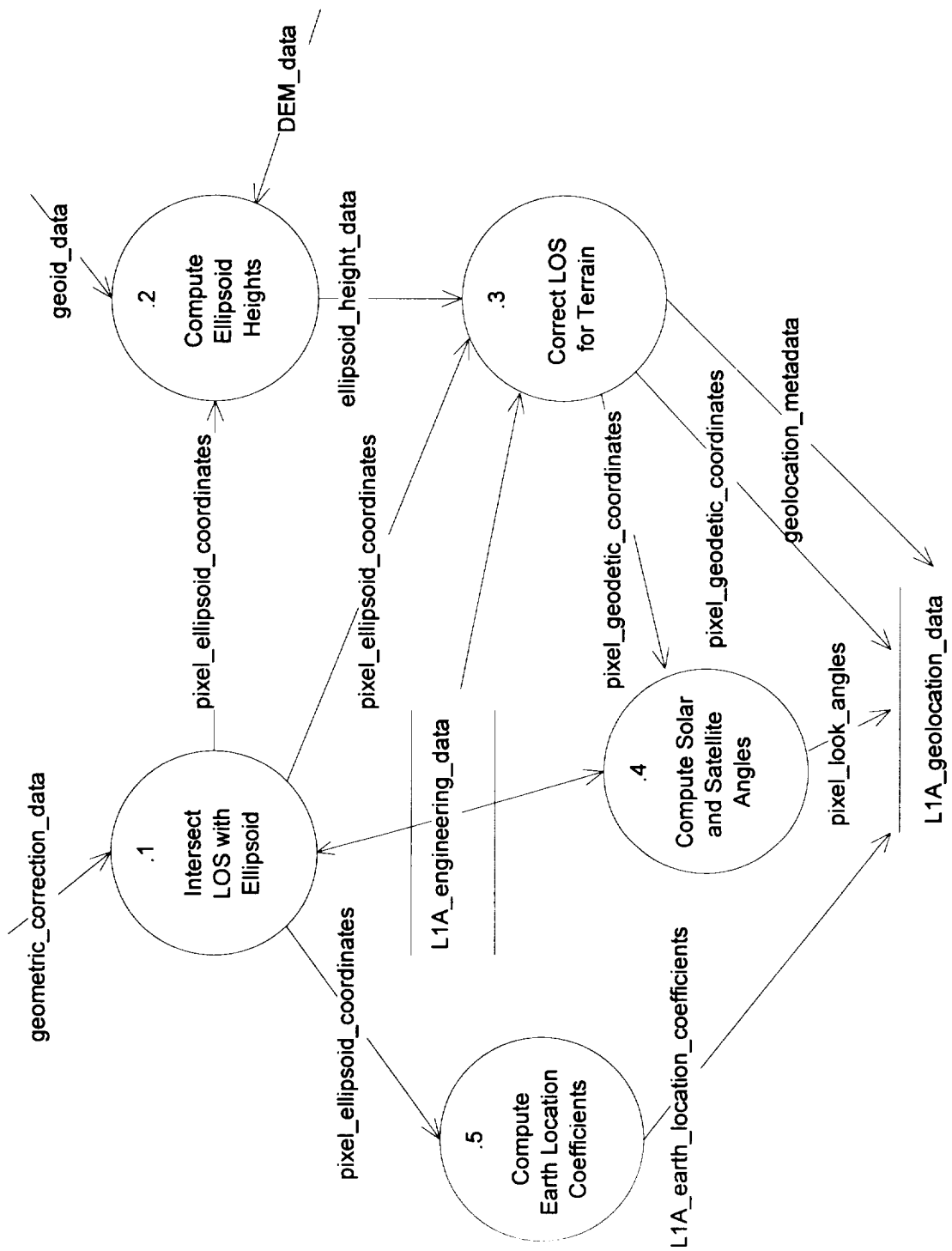
 Update orbit/attitude data flag

 Write orbit to L1A_engineering_data

 Write attitude to L1A_engineering_data

End if

Report processing status



Geolocation Level 1A Pixels

Intersect LOS with Ellipsoid

TITLE:

Intersect LOS with Ellipsoid

INPUT/OUTPUT:

L1A_engineering_data : data_in
geometric_correction_data : data_in
pixel_ellipsoid_coordinates : data_out

BODY:

```
Read orbit data
Read attitude data
Read geometric_correction_data
For each scan
    Read mirror data
    Read scan time
    For each data frame
        Compute imaging time
        Interpolate orbit
        Interpolate attitude
        Interpolate mirror position
        For each pixel
            Construct sensor line of sight
            Solve look point equation
        End loop
    End loop
    Write pixel_ellipsoid_coordinates
End loop
Report processing status
```


Compute Ellipsoid Heights

TITLE:

Compute Ellipsoid Heights

INPUT/OUTPUT:

pixel_ellipsoid_coordinates : data_in

geoid_data : data_in

DEM_data : data_in

ellipsoid_height_data : data_out

BODY:

Read pixel_ellipsoid_coordinates
Determine region of interest for L1A data
Get geoid_data for L1A region from PGS
Get DEM_data for L1A region from PGS
Convert DEM elevations to ellipsoid heights
Write ellipsoid_height_data
Report processing status

Correct LOS for Terrain

TITLE:

Correct LOS for Terrain

INPUT/OUTPUT:

L1A_engineering_data : data_in
pixel_ellipsoid_coordinates : data_in
ellipsoid_height_data : data_in
pixel_geodetic_coordinates : data_out
geolocation_metadata : data_out

BODY:

```
Read orbit data
For each scan
    Read pixel_ellipsoid_coordinates
    For each data frame
        Compute imaging time
        Interpolate orbit
        For each pixel
            Construct line of sight
            Iterate to convergence
                Interpolate ellipsoid height
                Solve look point equation
            End iteration
        End loop
    End loop
    Write pixel_geodetic_coordinates
End loop
Write geolocation_metadata
Report processing status
```

Compute Solar and Satellite Angle

TITLE:

Compute Solar and Satellite Angles

INPUT/OUTPUT:

L1A_engineering_data : data_in

pixel_geodetic_coordinates : data_in

pixel_look_angles : data_out

BODY:

Read orbit data

Read sun vectors

For each scan

 Read pixel_geodetic_coordinates

 For each data frame

 Compute imaging time

 Interpolate orbit

 Interpolate sun vector

 For each pixel

 Compute satellite zenith angle and azimuth

 Compute satellite range

 Compute solar zenith angle and azimuth

 End loop

 End loop

 Write pixel_look_angles

End loop

Report processing status

Compute Earth Location Coeff

TITLE:

Compute Earth Location Coefficients

INPUT/OUTPUT:

pixel_ellipsoid_coordinates : data_in

L1A_earth_location_coefficients : data_out

BODY:

P-Spec empty.

Append Geolocation Data to Level 1A

TITLE:

Append Geolocation Data to Level 1A Orbit

INPUT/OUTPUT:

L1A_geolocation_data : data_in

L1A_orbit : data_in

L1A_geolocated_orbit : data_out

geolocation_metadata : data_out

BODY:

Read L1A_orbit scan cubes

Read L1A_geolocation_data

Add geolocation data layers to scan cubes

Read L1A_orbit header

Write L1A_geolocated_orbit

Add L1A_earth_location_coefficients to geolocation_metadata

Write geolocation_metadata

Report processing status

Measure Geometric Distortion

TITLE:

Measure Geometric Distortion

INPUT/OUTPUT:

ground_control_data : data_in

geometric_correction_data : data_in

L1A_geolocated_orbit : data_in

geometric_distortion_data : data_out

BODY:

* Use ground control image chips to measure the residual geometric error in the L1A product using the 250 meter resolution data. *

Read ground_control_data pointer

If not null

 Read ground_control_data

 Loop on number of control points

 Extract 250 meter image data from L1A_geolocated_orbit

 Assess control point suitability

 If control point is good

 Measure geometric error at control point

 Add to geometric_distortion_data

 End if

 End loop

 Write geometric_distortion_data

End if

Report processing status

ancillary_geolocation_data (data flow) =

All geolocation input data not part of level 0 raw data

geometric_correction_data +
DEM_data +
geoid_data +
(orbit_attitude_data)+
(ground_control_data)

control_from_PGS (control flow) =

L1A_control_from_PGS +
L1B_control_from_PGS +
higher_level_control_from_PGS
consists of all control information from the PGS toolkit

DEM_data (data flow) =

A model of the Earth's terrain expressed as elevation above mean sea level with corresponding data quality information. Additional terrain characteristics may be required by other processes but the elevation and elevation quality data are of interest for Level 1A processing. The precise contents (including accuracy and spatial resolution) of this data set is TBD. Access to this ancillary data set will be provided via the PGS Tool Kit..

EDOS_accounting (data flow) =

not-defined.

ellipsoid_height_data (data flow) =

A representation of the Earth's terrain in the region covered by the Level 1A data set, expressed as height above the Earth ellipsoid. This is generated by combining the DEM elevation data and the geoid separation..

geoid_data (data flow) =

*A model of the deviation of the Earth geoid from the nominal

Earth ellipsoid surface which provides a numerical representation of the mean sea level surface. This is an ancillary data set provided via the PGS Tool Kit. This data set will not be necessary if the global DEM data are stored as ellipsoid heights rather than elevations above mean sea level.*.

geolocation_metadata (data flow) =

Information describing the geolocation processing, to be included in the data set metadata. This includes the source of orbit/attitude data used (LO or PGS), the availability and quality of terrain information, the geometric correction data used, and other TBD fields..

geometric_correction_data (data flow) =

Constants describing the internal geometry of the MODIS instrument and its relationship to the EOS platform (e.g. the sensor to body alignment matrix, detector offsets, band offsets). These parameters will be known to some precision at launch and will be refined post-launch through an ongoing geometric correction effort.

geometric_distortion_data (data flow) =

Measured geometric error at ground control points. Examples of specific fields include GCP latitude, longitude, and height, predicted pixel/line, actual pixel/line, and control point image chip correlation statistics..

ground_control_data (data flow) =

Image points with known ground positions. Examples of specific contents include an image window (chip), latitude, longitude, and height of the control point, and the subpixel location of the GCP within the image chip..

higher_level_control_from_PGS (control flow) =

*Defined as all control of the higher level processing provided by the PGS toolki

higher_level_data_products (store) =

Defined as all data products produced beyond level 1B.

level_2_data_products +
level_3_data_products +
level_4_data_products

higher_level_status_to_PGS (data flow) =

All higher level status returned to the PGS toolkit from the MODIS data processing system

l2_status_to_PGS +
l3_status_to_PGS +
l4_status_to_PGS.

L0_packets (data flow) =

Defined as all level 0 packets in the MODIS dataset.

L0_MODIS_packets +
L0_EDOS_accounting_packets

L0_verified_information (data flow) =

*Defined as validated MODIS instrument data. *

L0_verified_sensor_data +
L0_verified_engineering_data +
time_tag

L1_to_L4_MODIS_products (data flow) =

*Defined as all MODIS Data Products
delivered to the MODIS Science Team by the data system.*

level_1A_data_product +
level_1B_data_product +
level_2_data_products +
level_3_data_products +
level_4_data_products

L1A_control_from_PGS (control flow) =

*Defined as all control of the L1A processing provided by the PGS toolkit *.

L1A_earth_location_coefficients (data flow) =

*Coefficients of a low order model which describes the
relationship between image pixel-line coordinates and
ground coordinates. These coefficients provide rapid
spatial indexing from ground to image or image to ground *.

L1A_engineering_data (store) =

Platform and sensor data needed to perform Earth location

L0_orbit_attitude
+ L0_solar_vector
+ L0_scan_mirror_data
+ L0_scan_time_data
+ (orbit_attitude_data) .

L1A_geolocated_orbit (store) =

L1A data with Earth location information appended

L1A_orbit
+ pixel_geodetic_coordinates
+ pixel_look_angles
+ L1A_earth_location_coefficients

L1A_geolocation_data (store) =

Earth location data added to L1A product

pixel_geodetic_coordinates
+ pixel_look_angles
+ L1A_earth_location_coefficients
+ geolocation_metadata .

L1A_orbit (store) =

not-defined.

L1A_scan_cube (store) =

The L1A_scan_cube is fully defined in a separate document. See Tom Goff of the SDST for further details.

L0_verified_information +
sensor_data_quality

L1A_status_to_PGS (data flow) =

not-defined.

L1B_control_from_PGS (control flow) =

*Defined as all control of the L1B processing provided by the PGS toolkit *

L1B_status_to_PGS (data flow) =

not-defined.

level_1A_data_product (store) =

*Defined as all level 1A data products

This is a full orbit's worth of data. The unit will begin and end at the ascending node of the orbit. This product will be in HDF format.*

L1A_data_product_header +
L1A_scan_cubes

level_1A_metadata (store) =

not-defined.

level_1B_data_product (store) =

level_1B_geolocated_datasets +
level_1B_calibrated_datasets.

level_1B_metadata (store) =

not-defined.

misc_L1A_input_data (data flow) =

*all other L1A_input_data not included in
ancillary_geolocation_data*

misc_L1A_output_data (data flow) =

*Other TBD output data created by the L1A
process excluding geometric_distortion_data*.

MODIS_level_0_Data (data flow) =

level_0_instrument_housekeeping +
level_0_science_data +
level_0_EDOS_header +
level_0_DADS_header.
*The Level 0 Modis Data
originates in the DADS and is defined as:

MODIS Instrument Housekeeping
MODIS Science Data
EDOS Headers*

MODIS_level_0_data (data flow) =

[MODIS_level_0_data_standard
| MODIS_level_0_data_quicklook
]

*Defined as a TDRSS contact. This may be a fraction of
or multiple orbits.

The Level 0 datasets sent by EDOS may be either the standard production oriented product
or a quicklook version of the data. The quicklook data is not a fully processed
level 0 dataset

MODIS_log_entries (data flow) =

*Defined as all log entries made to the MODIS logging
system. Includes an audit trail of all MODIS Processing.*.

orbit_attitude_data (data flow) =

*Satellite ephemeris and attitude data provided from
an external source via the PGS Toolkit.*.

Other_Data (data flow) =

Other_Input_Data is defined as all other datasets required to process the MODIS data.

other_higher_level_input_data (data flow) =

other_higher_level_output_data (data flow) =

not-defined.

other_input_data (data flow) =

other_L1A_input_data +
other_L1B_input_data +
other_higher_level_input_data.

*This represents all the input datasets required to process the MODIS data that the science team provides. This may include
coefs_from_science_team +
other_input_from_sci_team +
*

other_L1A_input_data (data flow) =

*All input data required for Level 1A data processing not provided by the spacecraft

misc_L1A_input_data +
ancillary_geolocation_data

other_L1A_output_data (data flow) =

Additional output data sets created by the MODIS Level 1A process

geometric_distortion_data +
misc_L1A_output_data

other_L1B_input_data (data flow) =

*All input data required for Level 1B data processing not provided by the spacecraft

other_L1B_output_data (data flow) =

*Additional output data sets (other than data products)
created by the MODIS Level 1B process*

other_L2_input_data (data flow) =

*All input data required for Level 2 data processing not provided by the spacecraft

other_output_data (data flow) =

other_L1A_output_data +
other_L1B_output_data +
other_higher_level_output_data

*This represents all additional output data sets
created by the MODIS processing system. Examples
include geometric correction parameters. *

PGS (data flow) =

Product Generation System component of the EOSDIS Core System.

pixel_ellipsoid_coordinates (data flow) =

*The geodetic longitude and latitude at which each nominal
1 km IFOV line of sight intersects the Earth ellipsoid.*.

pixel_geodetic_coordinates (data flow) =

*Geodetic longitude, latitude and ellipsoid height for each
nominal 1 km IFOV in a Level 1A data set.*.

pixel_look_angles (data flow) =

*Solar zenith angle, solar azimuth, satellite zenith angle,
satellite azimuth, and satellite range for each spatial
element in a Level 1A data set.*.

processing_status (store) =
not-defined.

sensor_data_quality (data flow) =
not-defined.

start_L1A_processing (control flow) =
not-defined.

status_to_PGS (data flow) =

L1A_status_to_PGS +
L1B_status_to_PGS +
higher_level_status_to_PGS.
consists of all status information sent to the PGS toolkit

Appendix B
MODIS Level 1 Development Schedule

MODIS SDST SCHEDULE

ID	Name	1993			1994			1995			1996			1997			1998		
1	MODIS Level 1 Code Development																		
2	Beta Version																		
3	Develop Level 1A Code																		
8	Develop Level 1B Code																		
12	Develop Test																		
13	Internal Test																		
14	Test with SCF Beta Toolkit																		
15	Test on Beta ECS (Release 1)																		
16	Version 1																		
17	Develop Code																		
20	Develop Test																		
21	Internal Test																		
22	Test with SCF Revised Toolkit																		
23	Test on ECS (Release 2)																		
24	Version 2																		
25	Develop Code																		
28	Develop Test																		
29	Internal Test																		
30	Test with SCF Final AM Toolkit																		
31	Test on ECS (Release 3)																		

MODIS SDST1

11/30/93

Appendix C

MODIS Level 0 and Level 1A Data Rate and Volumes With the Proposed Computerized Data Structures

Appendix C

MODIS Data Rates, Volumes, and Processing Performance with the proposed Computerized Data Structures

This document is an evolving master list of the MODIS data rates and volumes expected from the MODIS instrument. Several assumptions have been made in order to provide these estimates and these are noted at the point the estimate is presented. An indication of the variance of these estimates is included as notes within each section. See the glossary at the end of this document for the definitions of MODIS instrument related item descriptions

The Data Products will be archived in the Hierarchical Data Format (HDF) which will require an agreed upon list of formal names for all parameters and dimension indices. These formal names will be presented in a spreadsheet format in future editions of this document, or as separate documents for each Data Product.

Assumed, currently accepted constants

- Scan Period: 1.47717 sec/scan (not the mirror rate) (SBRC 9/92)
- Orbital Period: 98.9 minutes = 5934 seconds (EOS-AM)
- 2 - 250 meter bands
- 5 - 500 meter bands
- 29 - 1 kilometer bands
- 2 - alternate gain channels (for bands 13 + 14) - These results give $(2*16+5*4+29+2=83)$ channels of science data per 1 km spatial element
- 10 detectors (for the 1km bands, 20 for 500m bands, 40 for 250m bands) in the along track direction form a frame of data (simultaneous readout)
- 1354 science frames per scan (705 km satellite altitude, $\pm 55^\circ$ scan angle)
- 50 solar diffuser (SD) frames per scan
- 5 spectroradiometric calibrator (SRCA) frames per frame
- 30 black body (BB) frames per frame
- 15 space view frames per frame

- 2 engineering data frame equivalents (1 engineering and 1 memory dump) - These results give $50+5+30+15+1354+2=1456$ data frames per scan (SBRC 3/93)
- 12 bits per pixel for all science, SD, SRCA, BB, and space view detector readout data (SBRC 3/93)
- 14,956,032 bits per day mode scan (SBRC 9/92) - This number includes all science, calibration, engineering, and CCSDS header/trailer bits
- 2,733,170 bits per night mode scan (SBRC 9/92)
- day/night mode mix = 50% day, 50% night (60% day, 40% night would be a 60% duty cycle). (Day mode includes all 36 bands, night mode is limited to bands 20 through 36.)

MODIS Scan Frame and Telemetry Packet Sizes (day and night mode):

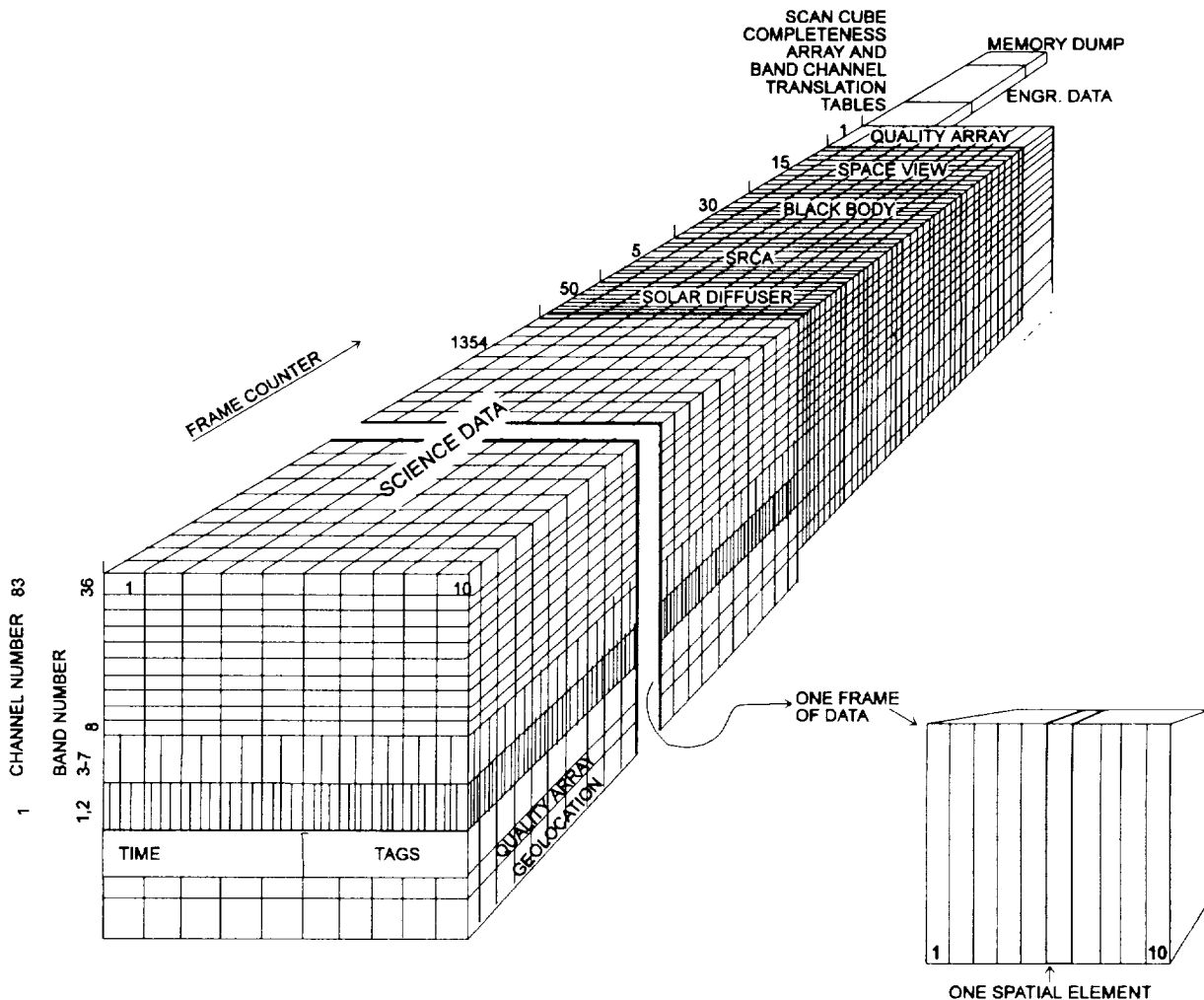
- 4980 data bits per frame segment (one segment per packet), two segments per day mode frame (83 channels * 10 detectors along track * 12 bits per detector / 2 segments per frame)
- 2040 data bits per night mode frame (17 channels * 10 detectors * 12 bits per detector), unsegmented packets
- 108 bits for secondary header and check sum
- 48 bits for CCSDS header
- 5136 day mode bits or 2196 night mode bits per CCSDS packet

Derived Packet Transfer Rates:

- 14,956,032 bits per day mode scan (2 day mode packets per frame * 1456 frames per scan * 5136 bits per packet)
- 4,021,128 bits per night mode scan (1 packet per frame * 1354 frames per scan * 2196 bits per packet + 2 packets per frame * 102 frames per scan * 5136 bits per packet)
- 10.124787 megabits per second, day mode (14,956,032 bits per scan / 1.47717 scans per second)
- 2.722183 megabits per second, night mode (4,021,128 bits per scan / 1.47717 scans per second)

Basic Derived Scan Cube Results (day and night mode):

- 4017.14 scans per orbit (98.9 minutes per orbit * 60 seconds per minute / 1.47717 scans per second)
- 14.56 orbits per day (24 hours per day * 60 minutes per hour / 98.9 minutes per orbit)
- 58,490.22 scans per day (24 hours per day * 60 minutes per hour * 60 seconds per minute / 1.47717 scans per orbit)



Level-0 Data Volume and Rates: MODIS will be in one of two major modes: day or night. (A mode which schedules solar diffuser data deletion is mentioned in the references. This may affect the number of data frames in a scan cube)

- 1456 data frames per scan * 2 long (5136 bits) packets per frame = 2912 packets per scan (day mode)
- 1456 data frames * 1 short (2196 bits) packet per frame = 1456 packets per scan (night mode)
- 1354 data frames * 1 short (2196 bits) packet per frame plus 102 (full) frames (times 2 packet segments per frame) = 1550 packets per scan (night mode). All bands (long segmented packets) for non-science data at night is an assumption.
- for a 50/50 day/night orbital mix, $2912 \text{ packets/scan, day mode} * 5136 \text{ bits/packet} + 204 \text{ long packets/scan} * 5136 \text{ bits/packet} + 1354 \text{ short packets/scan} * 2196 \text{ bits/packet} * 4017 \text{ scans/orbit} / 2 (50/50\% \text{ mix}) / 8 \text{ bits/byte} = 4.76445 \text{ gigabytes per orbit}$

- for 14.56 orbits per day = **69.37 gigabytes per day**, assuming the night mode non-science frames are of the long packet type. This does not include any EDOS accounting information.
- $7.5101\text{e}9$ bytes per orbit = 7.51 gigabytes per orbit, 100% day rate
- $1.0935\text{e}11$ bytes per day = 109.35 gigabytes per day, 100% day rate
- $1.3724\text{e}9$ bytes per orbit = 1.37 gigabytes per orbit, 100% night rate, assuming the non-science frames are of short type
- $1.9983\text{e}10$ bytes per day = 19.98 gigabytes per day, 100% night rate (short non-science frames)
- 64.67 gigabytes per day, 50/50% day/night mix (if the short non-science night mode frames are constrained to 17 data channels)
- Level-0 ancillary (accounting, metadata) are to be determined (TBD) and supplied by the EDOS design team.

These data estimates can be considered to be fully accurate with essentially no variance, assuming that all frames of data are continuously sampled. It is assumed that the solar diffuser (SD) frame data will be enabled for all orbits or the major part of a selected orbit and will be a normal component of the scan cube. If the SD data is scheduled to be deleted from the scan data, the data rate will reduce by 3.4% (50 divided by 1456 frames) of the full data rate by disabling the SD frame data. This may occur for a small fraction of an orbit at a TBD interval (monthly perhaps). Other data frames are assumed to be always present (not selectively scheduled).

Structure of the Level-0 Data Product

The structure of the Level-0 Data Product and the Level-0 accounting (metadata) product will be determined by the MODIS instrument builder (Hughes SBRC) and EDOS respectively. The sizing information within this document is based on the best available information available to the MODIS SDST at the time this document is updated.

Level-1A Data description:

The Level-1A data Product Generator is expected to produce two data products: the Level-1A Data Product and the Level-1A Metadata. These products will be produced for both standard and quick look data transmission modes. The Level-1A Data Product consists of three components: the science data (ground looking), the calibration data (solar diffuser, black body, space view port, etc.), and the engineering data (housekeeping, memory dumps). Data volumes are presented as scan cube estimates with orbital and daily volumes summarized at the end of this section. A visualization of a scan cube is conceptualized in Figure 1.

An important concept: *Science data are obtained from 36 frequency bands, but is organized into 83 data channels as follows:* One kilometer spatial views are designated as spatial elements and consist of 16 - 250 meter IFOVs for each of bands 1 and 2, 4 - 500 meter IFOVs for each of bands 3 through 7, and 1 - 1 kilometer IFOV for each of bands 8 through 36. Bands 13 and 14 have two data channel values (high/low gains at separate detectors) per band. This results in 83 data channels per 1 km spatial view. Data is assumed to be taken for all channels during the calibration phase even if the data is inapplicable (for example: solar diffuser data during MODIS night mode).

A frame of data consists of the above mentioned 83 data channels multiplied by the 10 (or 20 or 40) along track detectors. Visualizing the scan cube as a loaf of store bought bread, a frame of data would be equivalent to a slice of bread, and a loaf would contain 1456 slices. This loaf of bread would be flying through space sideways (laterally), which is also how the MODIS instrument will travel in orbit (see Figure 2).

Science Data - day mode

- 12 bits per science data value (pixel) unpacked and byte aligned into 2 byte (16 bit) words. This is the current assumption for the Level-1A Data Product.
- $2 \times 16 + 5 \times 4 + 29 + (2 \text{ dual gain}) = 83$ data channels (IFOV data values) per spatial element
- 10 along track spatial elements per frame
- 1354 across track frames per swath (half mirror rotation, one scan)
- 1,123,820 day mode science data values per scan cube. (83 channels * 10 spatial elements per frame * 1354 frames per scan)

Science Data - night mode

- 12 bits per science data value (pixel) unpacked and byte aligned into 2 byte (16 bit) words (assumed)
- 17 bands (IFOV data values) per spatial element (bands 20 through 36)
- 10 along track spatial elements per frame
- 1354 across track frames per swath
- 230,180 night mode science data values per scan cube (17 channels * 10 spatial elements per frame * 1354 frames per scan)

Calibration Data - solar diffuser (SD)

- 83 channels per 1 km spatial element
- 50 frames of data values
- 10 elements per frame

- 41,500 solar diffuser data values per scan cube ($= 83 * 50 * 10$) (when scheduled)

Calibration Data - spectroradiometric calibrator (SRCA)

- 83 data channels per 1km spatial element
- 5 frames of data values
- 10 elements per frame
- 4150 SRCA data values per scan cube

Calibration Data - black body (BB)

- 83 bands per element
- 30 frames of data values
- 10 elements per frame
- 24,900 black body data values per scan cube ($= 83 * 30 * 10$)

Calibration Data - space view

- 83 bands per element
- 15 frames of data values
- 10 elements per frame
- 12,450 space view data values per scan cube ($= 83 * 15 * 10$)

Engineering & Memory Dump Data

- low rate housekeeping data (This is a guess based on data available in 1991)
69 Boolean values
48 analog values
- spacecraft ancillary data (?). Note that the original concept for obtaining the spacecraft position and attitude information assumed that this information would be contained within a separate packet stream, not a part of the MODIS data. However, the spacecraft will have the TONS system onboard which will provide this data on the spacecraft data bus. Detailed specifications (values and first derivatives) and data update rates are TBD.

The engineering data that is listed in the following items is currently assumed to be sampled at the MODIS 12 bit precision. These values will be used to measure the references to be used in the calibration techniques. A case can be made to improve the precision of these measurements (possible to 16 bits) because the precision of the measuring device should be greater than the precision of the item under measurement.

- raw black body temperature data

12 sensors with 12 (or more) bits per sensor

- solar diffuser stability monitor (SDSM) sensor data (?). The spectral emissions of the solar diffuser plate.
- SRCA self calibrate and reference diode data (?)
- scan mirror linearity time data (?). Perhaps a time based encoder readout of the mirror position at selected scan frame clock times?
- status information (?). Will this include a repeat back of the MODIS Commands and/or instrument states?
- DC restore offset data (?). Assumed to be for each data channel! What about the data channels that have more than one detector?
- memory used for functional control (?)
- format processor memory as scheduled (?). A computer memory dump.
- test and control processor memory as scheduled (?). A computer memory dump.
- *Engineering & memory Summary* - (not representative of the final values) (Any decommutation, conversion, or formatting is TBD. Note that the low rate data will be submultiplexed and carried in the data set header rather than the scan cubes)
 $2 \text{ frames} * 2 \text{ segments per frame} * 5136 \text{ bits per segment} = 20544 \text{ bits per scan}$
- 13540 georeferencing ground locations (one for each spatial element of 1354 frames * 10 elements per frame)

Level-1A Data volume and rates:

- 1456 frames per scan cube
- 83 channels (data values) per spatial element for day mode, 17 channels for night mode
- 10 spatial elements per frame
- 2 bytes per data value
- These result in 2,416,960 bytes of instrument data values per scan cube for day mode (1456 frames per scan * 83 data channels * 10 detectors along track * 2 bytes per data value)
- 629,680 bytes of instrument data values for night mode (1354 frames per scan * 17 data channels * 10 detectors along track * 2 bytes per data value + 102 frames * 83 data channels * 10 detectors along track * 2 bytes per data value)
- 8 georeferencing data values (real, floating point numbers) per spatial element. (geodetic latitude, longitude and height; solar zenith and azimuth angles; and instrument zenith and azimuth angles and slant range). This adds 433,280 bytes to both the day mode and the night scan cubes (13540 spatial elements * 8 data values * 4 bytes per data value).
- 13540 bytes for data quality (13540 spatial elements * 8 bits per element)

Possible decommutation and formatting of engineering data and reformatting of the SRCA data and the addition of an 8 bit index into the data quality array may increase these scan cube sizes.

The total computed summary for the **scan cube sizes** are : **2,863,780 bytes for day mode and 1,076,500 bytes for night mode**. Note that the spatial element georeferencing consumes 15.1 percent of the day mode scan cube and 40.2 percent of the night mode scan cube.

- 4017.14 scans per orbit gives a 100% day mode orbital data set size of 11.5042 gigabytes, including the header information, and 4.3245 gigabytes for night mode.
- For a 50/50 day/night split, $(11.5042 + 4.3245) * 50\%$, **7.916 gigabytes per orbital data set, 50/50% day/night split.**
- 14.56 orbits per day will produce 167.5 gigabytes of Level-1A Data Product per day for 100% day mode, 64.964 gigabytes per day for 100% night mode, **115.233 gigabytes per day for a 50/50% day/night split.**

These data sizes can be considered to be accurate to ± 3 percent. They include all detector, data quality, and georeferencing data but do not include the demultiplexing of any engineering, house keeping, or memory dump data.

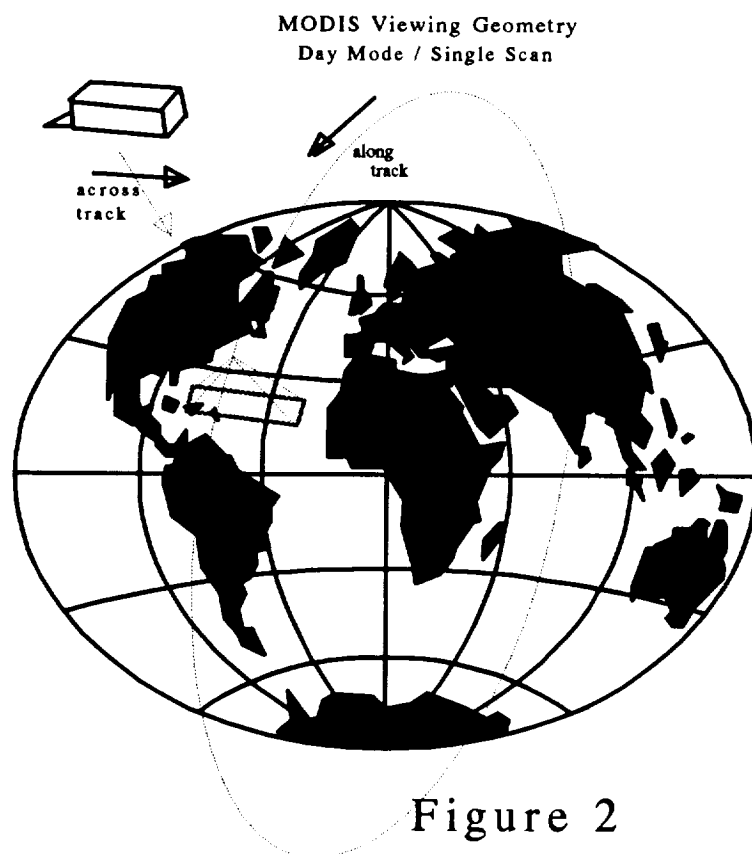
Note that data compression is not a consideration at the present time. If data compression will be employed, then a fixed length scan cube for both day and night mode would simplify the logical organization of the data structure by allowing bands 1 to 19 to be included in the night mode scan cube without a storage penalty.

Structure of the Level-1A Data Product

The Level-1A Data Product will be generated as two data sets: the Metadata and the Data Product. The Metadata will consist of the Level-0 accounting data (an early type of metadata) with any MODIS Level-1A derived information appended. This value added data is expected to be a synopsis of the Data Product, indications of the completeness and quality of the data, and any outside user comments on the data. Any structure for this metadata will be determined by the EOS project, CCSDS recommendations, and Science Team member input.

The Level-1A Data Product will consist of a header and multiple occurrences of the scan cubes. The header information will contain free field (ASCII) information, completeness and quality information in both ASCII and binary forms, instrument anomalies, spatial coverage, geolocation parametric data, memory dump data, and all other data set related information. The quality information in the header will apply to the complete collection of scan cubes. Detailed quality about an individual scan cube will be included with each scan cube and summarized in the header. Header information (other than the geolocation parametric data) is repeated in the metadata.

Each scan cube, as illustrated in Figure 1, will contain all the data obtained from the instrument frames, segmented spacecraft time (MODIS and platform) at each frame, mirror side, source identification, and configuration indications. This will apply to the solar diffuser, spectroradiometric calibration array, black body, space view, and science view (Earth) data portions of the scan. Adjacent to the science data portion of the cube will be the Earth georeferencing location and geometry array for each spatial element and a data quality array for each spatial element. Following the scan cube will be the Engineering Frames (data representations, decommutations, and formatting are TBD), and a detector quality, two dimensional array for each data channel (83 channels by 10 along track 1 km spatial elements).



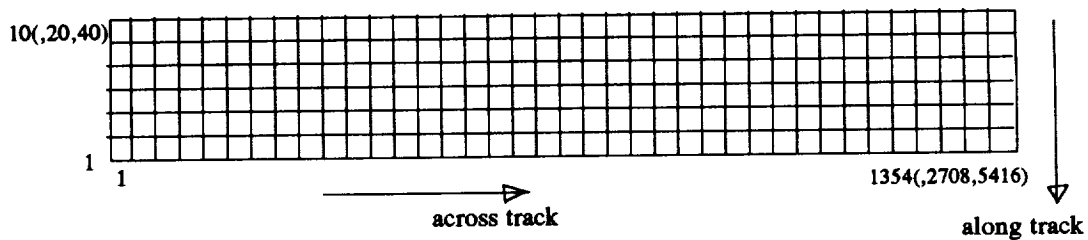


Figure 3 - Pixel Numbering Scheme

Most of the data processing to be performed in the following Level-2 processes will be performed on a pixel by pixel basis. This suggests that the internal scan cube structure should be stored with all bands of data for one spatial element in adjacent memory locations. Unfortunately, this could only be accomplished with a complicated variable length indexed data structure which could not be implemented or accessed in FORTRAN. Also, computer systems that are currently available and will be enhanced in the future, can handle the direct addressing of three megabyte arrays with no penalties. Plus, the data quality array further complicates any direct easy access to the data structure. Therefore, the internal data structure will be principally based on the concept of the 1 km spatial element with 83 channels of data, in place of a logical 36 band based structure. Data can be accessed by a band and IFOV location which will be translated into the internal channel and spatial element location via included translation tables. This allows the science data to be accessed via the logical spatial index while the internal data cube representation retains the square indices.

The data set will be placed into the HDF representation which is in the process of being upgraded for use by the NASA DAACS. Facilities within the HDF technique in the future may allow for indexing, that could simplify the data structure as presented here. The VSET capability in HDF will allow the georeferencing to be applied to the Level 1A, 1B, and 2 data sets concurrently without a storage penalty. Georeferencing can be extracted and appended to distributed data sets as needed.

The major components of the Level-1A output Data Product structure with descriptors are listed in the following item list.

MODIS Level 1A Data Product Header

- Source of the data set
- spatial extent -coverage at nadir and selected latitudes
- temporal extent - date, time, and ephemeris
- georeferencing parameters - a set of coefficients that will allow the data set to be geolocated to less accuracy than the georeferenced spatial element points. The SDST will supply a software function that will allow MODIS data product users to determine the ground location, given these parameters.

- pointers to all related data sets - metadata, calibration measurements, DEM, etc

MODIS Level 1A Data Product Scan Cubes

- Raw Science Data - three dimensional array - along track, across track (= scanwise), band number
- Raw Solar Diffuser Data - three dimensional array - along track, scanwise, band number
- SRCA Data - three dimensional array - along track, scanwise, band number
- Raw Black Body Data - three dimensional array - along track, scanwise, band number
- Raw Space View Data - three dimensional array - along track, scanwise, band number
- Band Number to Data Channel translation tables - three tables that translate the logical along track index, the logical across track index, and the band number into the three dimensional cube data channel array indices. Note that the logical cube indices have differing ranges as a function of the band number.
- Spatial Data Quality - two dimensions - along track, across track at 1 km indices. Eight bits will allow 255 possible quality specifications to be determined on a per spatial element basis.
- Time Tag - array with two tags per frame for day mode, one tag for night mode. This will be subdivided into the various time elements when they have been further specified by EOS and SBRC.
- Geolocation - a set of real (floating point) values that specify the latitude, longitude, solar zenith, solar azimuth, instrument zenith, instrument azimuth, and instrument range for each 1km spatial element. These are not the parametric coefficients included in the data set header that are used for less accurate geolocation.
- SDSM - The view direction and integrating sphere data readouts.
- Engineering / Memory Dumps - these are a set of sequential variables or linear arrays, the format and contents of which are (TBD). Note that the memory dumps and many engineering readings are sampled at a much lower rate than the scan cube rate. These data will be submultiplexed within this data area.
- Band Quality - array - the data quality specified for all IFOVs combined, one index per data channel.

A parametric software routine giving the ground location of any science data value will be provided as part of the Data Product header data structure specifications. An array of data quality descriptors in ASCII form, given the data quality index number, will also be included in the scan cube specification. These items will be derived at a future date.

Bands 13 and 14 have both a high gain and a low gain data channel, corresponding to the two detectors for each of these bands. For the purposes of the Level 1A Data Product, which contains the raw instrument counts, the high gain channels will be accessed as logical bands 37 and 38.

Coordinate System

The scan cube coordinate system, illustrated in figure 2 and further defined in figure 3, follows the SBRC detector numbering scheme with 40 detectors for bands 1 and 2, 20 detectors for bands 3 to 7, and 10 detectors for the remaining bands in the along track direction and 5416, 2708, and 1354 frames of detector readouts, respectively, in the across track (along scan) direction. This coordinate system will follow through (using the same scheme) for the solar diffuser, SRCA, black body, and space view data.

The illustration in figure 2 shows a view of the Earth, looking from the Sun, during a day mode, descending orbital pass. The EOS-AM orbit plane will be inclined 8 degrees from vertical as shown. This corresponds to an orbital inclination of 98 degrees. The satellite will pass over the equator at 10:30 am local time. This corresponds to a 22.5 degree rotation about the Earth vertical axis in the westerly direction. A scan cube at the equator during the day mode, will be 'tilted' 8 degrees clockwise as viewed from above. The MODIS instrument will scan from left to right, and generate successive scan cubes from top (north) to bottom (south). The nighttime pass will 'tilt' 8 degrees at the equator in the counterclockwise direction, create scan cubes south to north and scan right to left as viewed from a point opposite the Sun.

The current pixel numbering scheme uses increasing numbers in the scan direction, but decreasing numbers in the along track dimension. Numbers in parentheses in the included diagram represent the limits of the pixel numbering for the 500 meter and 250 meter bands respectively. Pixel numbering for the solar diffuser, black body, and space view will follow the same along track system but will have across track limits to match the number of data frames.

Level 1A Profiling and Computing Resources

Input / Output Rates

Note that any data staging by the DADS or other facilities in the data transmission chain are not included in this discussion.

- One long packet of 5136 bits = 642 bytes, short packet of 2196 bits = 275 bytes.
- 2912 packets per day mode scan, 1354 short and 102 long packets per night mode scan, 4017.14 scans per orbit, and an orbital period of 98.9 minutes give an input channel rate of 1510.32 packets per second orbital average.
- The maximum input packet size (day mode) gives a real time maximum Level-0 input rate of .9696 megabytes per second.
- A day mode scan cube size of 2.9 megabytes every 1.47717 seconds gives a maximum Level 1A output rate of 1.963 megabytes per second.

- A night mode scan cube size of 1.1 megabytes every 1.47747 seconds gives a maximum Level 1A output rate of .75 megabytes per second.

Processing Power

The following numbers represent a best guess and do not represent any detailed design or prototyping efforts at the present time.

- Incoming packet validation - (2 mips estimated)
- Placement of instrument data from packets into scan cubes - 1.208 million detector values ($1456 \times 10 \times 83$) per scan cube with <20 operations (2 loads, 1 store, 1 and, 12 shifts, 1 or) = 24,160,000 operations per scan cube
- Georeferencing for each of the 13540 spatial elements (from the "MODIS Level 1A Geolocation Processing Estimate" internal document. A total of 41.4 mflops, with the following breakdown:
 - geolocation to the ellipsoidal Earth - 1,519,188 operations per scan cube (657 multiplies, 373 adds, 70 trigometric, and 22 square roots per frame * 1354 frames per scan cube)
 - Digital Terrain Model (DTM) correction - 1,632,924 operations per scan cube (686 multiplies, 438 adds, 56 trigometric, and 26 square roots per spatial element * 1354 frames per scan cube * 10 spatial elements per frame)
 - ancillary angle (zenith and azimuth) determination - 1,221,308 operations per scan cube (512 multiplies, 268 adds, 82 trigometric, and 40 square roots per frame * 1354 frames per scan cube)
- Allowing for data quality testing, message passing, possible packet ordering, engineering data organization and validation, etc. an initial guess of ~20 mips multiplied by suitable scaling factor (TBD) would be appropriate.
- Scan cube handling overhead - 1 mips estimated.
- TOTAL Processing Power (assuming mips = flops) = 88.5 mflops, minimum.

These results can be considered accurate for the I/O (input/output) rates, but highly speculative for the processing power estimates. Note that the I/O rates use relatively small data transfer sizes, resulting in a high I/O channel overhead. Blocking these packets into larger entities would produce a more efficient system from an I/O view point.

Important note: Possible future requirements that need to be kept in mind for the level 1A processing may include the determination of a land / water / cloud mask, the separation of ground truth data, or a target of opportunity algorithm such as a volcanology algorithm with location information to be passed to the ASTER team for rapid pointing to targets of opportunity.

GLOSSARY

- **Pixel** -The smallest decomposed unique science data value. One pixel represents the data from one spatial position and one channel of data.
- **Anchor Point Array** - a spatial array of Earth located positional values (latitude, longitude, and possibly elevation) that determines the location of a selected subset of the science data pixels.
- **Spatial Element** - all channels of data corresponding to a 1 kilometer ground equivalent field of view. This means that 16 - 250 meter detectors, 4 -500 meter detectors, and 1 - 1 km detector reside within one spatial element.
- **Channel** - the data derived from an instrument data gathering electronic channel. Channels of data may be obtained in parallel. Contrast this with a band of data.
- **Band** - A center frequency and filter function width combination that are referenced by an arbitrary number. One channel usually measures data from one band, but MODIS has two channels of data for each of bands 13 and 14.
- **Scan Cube** - The three dimensions of the science data: along track, across track, and band number with ground locations, engineering data (per scan), and quality indications attached.
- **Frame** - A set of data representing one instance of: all bands of science data and 10 along track spatial elements (day or night mode), or all bands & 10 spatial elements of solar diffuser, black body, or space view data, or specialized data from the SRCA or Engineering / Memory dumps.
- **Swath** - Engineering term for a half mirror rotation. This is equivalent to a scan cube.
- **Metadata** - Information describing the content, format, and utility of a data set.

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